Methods Matter: Computational Modelling in Public Health Policy and Planning

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Abstract

This work is aimed at understanding and unifying information on epidemiological modelling methods and how those methods relate to public policy addressing human health, specifically in the context of infectious disease prevention, pandemic planning, and health behaviour change. This thesis employs multiple qualitative and quantitative methods, and presents as a manuscript of several individual, data-driven projects that are combined in a narrative arc. The first chapter introduces the scope and complexity of this interdisciplinary undertaking, describing several topical intersections of importance. The second chapter begins the presentation of original data, and describes in detail two exercises in computational epidemiological modelling pertinent to pandemic influenza planning and policy, and progresses in the next chapter to present additional original data on how the confidence of the public in modelling methodology may have an effect on their planned health behaviour change as recommended in public health policy. The thesis narrative continues in the final data-driven chapter to describe how health policymakers use modelling methods and scientific evidence to inform and construct health policies for the prevention of infectious diseases, and concludes with a narrative chapter that evaluates the breadth of this data and recommends strategies for the optimal use of modelling methodologies when informing public health policy in applied public health scenarios.

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Preface

This dissertation is an original intellectual product of the author, J. Earnest. The work reported in Chapters 3 was covered by University of Glasgow IRB ethical approval for human subjects, and the GLEaM model that is the partial subject of Chapter 2 is the product of a large international collaboration who partially supported this work by hosting Rebecca Mancy and I at their lab. None of the text of the dissertation is taken directly from previously published or collaborative articles, however a manuscript derived from Chapter 3 has been submitted for review and publication to the journal Health Education and Behaviour as a collaboration between myself, Rebecca Mancy, Kate Reid, and Alexia Koletsou. The qualitative data collection and analysis in Chapter 3 was done primarily by myself with substantial collaboration from Alexia Koletsou, with supervision guidance from Rebecca Mancy. A research assistant, Richard Rhom, assisted with the entry and cleaning of quantitative data in Chapter 3, and the questionnaire used was adapted from Graham Lough's work in his master's thesis, with the rest of the quantitative analysis completed by myself and graphs generated by myself and Alexia Koletsou. The qualitative analysis in Chapter 4 was completed by myself, with framework development and coding validation from Kate Reid, and supervision assistance from Kate Reid.

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It's been my great privilege to produce this research with the support of a vibrant global community of world-class scientists, researchers, and policy professionals. I'm honoured to have Dr. Rebecca Mancy, Dr. Kate Reid, and Dr. Daniel Haydon as my supervisors, and I wish to express my sincerest gratitude for their expertise, time, and encouragement that enabled me to experience many successes and growth over the duration of my PhD. The University of Glasgow Lord/Kelvin Adam Smith Scholarship provided me with generous research support and professional opportunities without which none of this would be possible, and it has been my pleasure to be a member of this distinguished group of young scholars. I wish to extend the warmest thanks to my long-time mentor, Dr. Michael Yudell of Drexel University, both a brilliant scholar and a wonderful friend. Gratitude is also due to Dr. Alessandro Vespignani and the team of researchers who offered very generous support and guidance in the early days of this project, with very special thanks to Dr. Bruno Gonçalves for his wit, friendship, and encouragement. Thank you to the National Science Foundation, the European Social Simulation Association, the International Society for the Psychology of Science and Technology (ISPST), and The St. Andrew's Society of Philadelphia for supporting my work through bursaries and their recognitions of excellence. I'd also like to thank the US Dept. of Health and Human Services and the Oak Ridge Institutes of Science Education for an unforgettable internship experience on Capitol Hill, and particularly my colleagues there: Dr. Sharon Bergquist, Dr. Jennifer Gordon, Dr.Karin Bok, Neka Knapp, Mike Daley and Claire Slesinski. Thank you to Dr. Peter Barbrook-Johnson for sharing his research, Graham Lough for allowing his questionnaire to be adapted, Anna Beck for her support and friendship, and my intrepid research assistant, Richard Rhom.

Doctoral dissertations are a journey, and at times, a very challenging one. How lucky and deeply grateful I am to have warm and supportive colleagues to walk that path with. My research room, 683 St. Andrews, was a sanctuary and second home. The following people especially started as fellow students, and because of their grace and kindness are now friends forever: Dr. Alexia Koletsou, Dr. Natalie Watters, Dr. Katarzyna Borkowska, and Dr. Gail Goulet, Dr. Samantha Drake, Dr. Declan Baugh, and Brian D.Earp.

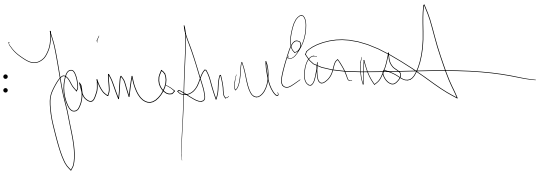
We are so much more than the things we accomplish, and the love of family and friends sit at the core of our beings, guiding us to our best selves and giving without expectation. Mom, everything I am I owe to you. This is yours as much as mine. I'm proud to be your daughter every single day. To my husband, Colin Forman, for his tireless goodness, humour, love, and faith in me. To my family Lisette, Lindsay, and Zach Morgan and to Dana and Nina Mauro and all of my cousins: thank you. Thank you to the Earnests.

To: Amanda Marie Santare, Bella, and the Santares, Elizabeth Ketterer DeLoggio, Peter, and her family, Michelle Simone Korman, Louisa Munday, Lauren E Ware Stark and the Wares, Jon Shapiro, Maria Raha, Claire Slesinski, Mike Matthews, Duncan CT Holyoke and Byron May, Dave Jaquette and the Jaquette Family, Ava Daugherty, Erica and Luis Flores and Liz Lyon, Christine Cloud O'Brien, Rebecca Clark, Jonathan Jackson, Drake Dwornik, and Desiree Fitterer Gregory: Thank you so very much for everything, my beautiful friends.

This thesis is dedicated in loving memory to Georgianna Jaquette Daugherty, JD.

Author's Declaration

I declare that, except where explicit reference is made to the contribution of others, that this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

Signature: 

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Chapter 1 – Modelling in Context

"The methods to aid decision makers are simply tools. They are tools for the willing clinician, they are tools for the worried patient. They are tools for the concerned policymaker and payer. They will not make a hazardous situation safe, nor will they make a lazy or incompetent clinician into a superior caregiver. If the methods do not eliminate controversy, they can clarify the reasons for difference of opinion. In dealing with the realities and uncertainties of life and illness, they will enable the thoughtful clinician, the thoughtful patient, and the open minded policymaker to make more reasoned conclusions"
– Dr. Harvey V. Feinberg, President, The Institutes of Medicine

1.1 Purpose

Public health policymaking seeks to address some of the most formidable social challenges facing contemporary human society. Meaningful, high-impact action is required to confront the threat of infectious disease to human health. Thus, understanding the ways in which actionable health policy is created and implemented, and the types of methods used to accomplish this, are of critical importance. Rütten (2012) critically notes, "Unlike the broad debate on the production of scientific evidence for informing policy and improving the policy content in public health, the production of evidence on the public health policy process itself is not well developed yet" (p.321). This body of research considers this process, and seeks to address three timely questions pertaining to the development of public health policies:

1) How is knowledge about the clinical characteristics of infectious disease, and the social-psychological characteristics of populations, best utilised in the process of modelling that underpins public health policies?

2) How does the widespread use of contemporary modelling tools to inform public health recommendations influence the public's projected health behaviour?

3) What are the challenges and processes policy stakeholders face when using modelling methods?

This body of work concludes with recommendations toward optimal use of scientific modelling in the public health policymaking process.

What follows in this introductory chapter is a brief description of the current evidence-based public health policy landscape, an overview of the role of modelling methods for this kind of policymaking, the contextual justification of the 3 major research questions addressed in subsequent chapters, with summaries of the 3 original research studies contained within the main body of the thesis that seek to address these questions.

Public health is, by its very nature, interdisciplinary and multi-method. This research seeks to reflect this interdisciplinarity by employing multiple modelling, quantitative, and qualitative methods to explore questions at the intersections of epidemiology, public health policy, risk communication, human behaviour change, and the modelling-based methodological approaches that unite them. While this chapter provides a brief overview of the evidence-based policy and modelling methods environment, in the spirit of the interdisciplinary nature of this work, each individual study in subsequent chapters addresses a different aspect of these intersections using diverse methods, and a more comprehensive, complete, and study-specific literature review and contextual background precedes each chapter.

1.2 Evidence-based Policy for Public Health

Public health policy is the primary means by which scientific evidence regarding health most directly and significantly influences individual lives. Government vaccination programs, climate change mitigation initiatives, and emergency preparedness plans for epidemic or pandemic disease are but a few examples of how evidence from public health science manifests itself into policies and public programs. Evidence-based policy for public health is rooted in the movement towards evidence-based medicine, where clinical decision making processes that emphasize explicit, data-justified management, treatment, and diagnosis have been the prevailing paradigm of practice and care for the past 20 years (Guyatt et al., 1992). This principle of using scientific evidence and methods to guide clinical treatment and health care operations is also now the prevailing model for the development of healthcare policy and public health practice.

The evidence and metrics that may be used to influence or inform public health policy can include both the quantitative (epidemiological or experimental) and the qualitative (narratives from interviews or other documents); and the use of that scientific evidence occurs in a wide variety of settings that range from legal, government, and civic organizations to clinical medical and social services provisions (Brownson, Chriqui, & Stamatakis, 2009).

As with clinical medical decision-making, the understanding in health policy is that the use of extensive and robust data to assist in the development of health policy will, by virtue of evidence-base, create the “greatest and most equitable” population health gains (Katikireddi, Higgins, Bond, Bonell, & Macintyre, 2011). However, public health policymaking and implementation are increasingly complex enterprises in the age of increased information and limited resources, and it is unlikely that there is a direct causal relationship between the use of evidence to inform policy and good health policies that always achieve optimal outcomes.

The evidence base needed to formulate policies that address the needs of large, diverse populations can itself be highly complex and large in scale and scope. But mere access to information, or even the ability to generate for-purpose data in the course of policy development, does not necessarily assure that the policies stemming from the use of evidence are ideally designed or well-implemented: “These are often complex, multifaceted programmes with important ethical and practical dimensions, but the same principles apply as in clinical care. Success of interventions depends on local feasibility, acceptability, and fit with context—and hence on informed, shared decision making with and by local communities, using summaries and visualisations of population level metrics” (Greenhalgh, Howick, & Maskrey, 2014 p3725).

There has been some discussion of how the various dimensions of evidence-based policymaking might be described, and how understanding those dimensions may play a role in generating solutions that would assist in optimising the policymaking process. Dobrow, Goel, & Upshur, (2004) identify what they deem as the “two fundamental components” of evidence-based policy: evidence and context. However, the authors note that it is the *interaction* between evidence and context, rather than the nature of the evidence or the context alone, which is the most crucial area of inquiry in the development of evidence-based health policy. They note that “Even when there is general agreement on what constitutes evidence, there is considerable observational work to suggest that the same evidence, utilised in different contexts, often leads to different decision outcomes” (p216).

Several other basic models of the evidence-based policy approach have been identified in the literature, yet none of them are particularly focused on the *processes* of evidence-based policymaking. These models, as identified and characterised through systematic review by Young, Ashby, Boaz, & Grayson (2002) include the: *knowledge driven model*, where research relevant to the policy topic actually leads and sets priorities for policy; the *problem-solving model*, where research follows policy and policy agendas are meant to shape the topics and agendas of research projects; and *the interactive model*, which is the model that is best fit for the concept of this body of research, in which research and policy agendas are informed by interaction with each other through "policy communities" (p216), wherein the interactions of policy stakeholders (including researchers), influences both policy and research agendas.

Young and colleagues (2002) also describe the *political/tactical* approach, which suggests that the contribution of research to policymaking is overshadowed by the need for most policy decisions to be politically expedient and politically strategic, and the *enlightenment model*, where research is a separate entity from policy entirely and is only occasionally utilised to inform policy, but is almost never the deciding or underpinning factor in a policy. These models each contribute some understanding to the various roles policy and evidence might play in the evidence-based policy process. Yet none of them completely characterise the *processes* by which policy and research interact to form an evidence-based research agenda. And while the *interactive* model suggests that policy and research do, in fact, inform and influence each other, it stops short at describing the specific domains of the evidence-based policy agenda.

1.3 Modelling in Policy

For that purpose, Brownson, Chriqui, & Stamatakis (2009) present the most cohesive, and widely accepted, characterisation of the process and creation of evidence-based policy. They describe 3 different domains of evidence-based policy: (1) *process*, the approaches to evidence-policymaking to enhance the likelihood of policy adoption; (2) *content*, specific policy elements that are likely to be effective; and (3) *outcomes*, the potential intended and unintended impact of policy. Brownson and colleagues further suggest that there are specific steps that can be taken to further the cause of evidence-based policy, including communicating and presenting data more effectively, using existing analytic tools more effectively, conducting surveillance to identify trends in policies, and tracking policy outcomes with different types of evidence. The various policymaking bodies engaged in public health policymaking may be tasked with performing the evaluation and use of different types of evidence from diverse sources across the aforementioned domains as identified by Brownson.

However, the account of how evidence is used in the process of public health policymaking is incomplete. Policymakers across settings are known to face political pressure and priorities that may be at odds with the scientific process or conflict with scientific findings, and these challenges can adversely affect their ability to use evidence optimally in any of the domains as described by Brownson. Early efforts to examine the role of scientific evidence as a regular component of public health policy identified a range of impediments to the evidence-based public health policy agenda that persist today (Black, 2001). For instance, policymakers may feel time pressure: a need for immediate scientific answers to complex health risk questions for which the evidence is uncertain or where actual scientific risk is at odds with the public perception of possible health risk (Greenberg, 1992). Policymakers may also experience pressure to implement policies based on political expedience to appease constituents and other invested policy stakeholders, rather than basing those policies on scientific evidence. Implementing, or refraining from implementing, the policy that the evidence suggests may be impeded by the lack of resources available to communities and governments, or by ethical and humane considerations (Black, 2001).

Policymakers may have legitimate, ethical reasons for rejecting policy options supported by scientific evidence, but it is noteworthy that they may use evidence improperly or incompletely to justify what is an ethical or humane policy decision when the pressure exists to justify every decision with data (Black, 2001). Further, scientific evidence may be rejected or overlooked by non-scientist policymakers in areas where understanding of conclusions often depends on what Black (2001) calls “tacit knowledge”. Tacit knowledge encompasses the idea that scientific literature is aimed at other scientists in fields relevant to the subject of the paper, and the language often assumes a certain amount of knowledge about, or familiarity with, the nomenclatures and subtleties of that area of scientific inquiry. So rejection of critical evidence, which has the potential to inform policy in a meaningful way, can happen due to *perceived* irrelevance of the findings by non-expert policymakers. This suggests that even when scientific evidence is readily available to policymakers that would like to utilise it, that utilisation is not necessarily optimal.

Despite these known challenges, there has been a steep increase in the demand that public health relevant policies be increasingly evidence-based and data driven, with Head (2010) noting that the evidence-based policy environment is becoming increasingly “supply and demand” driven, with the ‘needs’ of policymakers makers for “certain types of information about problems, programs and the effectiveness of options; and “supply” of an increased array of tools and techniques for analysis and evaluation of policy options that emerged over recent years. This call for a more interactive model of policy and evidence must be accompanied by a studied consideration of *how* evidence is being used in practice, and how to effectively use evidence in policymaking in the contexts in which it takes place.

Central to any consideration of the current state of evidence-based health policy is an examination of the dominant methods and sources of evidence used by policymakers in their endeavours. Modelling methods for complex systems, such as the ones that concern public health policymakers, involves the “use of formal models or simulations as explicit aids to increase our understanding of complex systems and improve the effectiveness of our actions within them” (Trochim, Cabrera, Milstein, Gallagher, & Leischow, 2006, p539). Modelling typically plays a central role in assisting decisions during the development of public health policy in two ways: 1) by serving as a platform for manipulating existing evidence by simulating or suggesting potential outcomes given specific parameters, typified by techniques such as deterministic compartmental modelling and stochastic individual-based or spatial models, and 2) by being used to generate needed data on policy-relevant questions such as cost-effectiveness or quality of life, for instance by the use of cost-utility models and quality-adjusted life years (QALYs) (Marsh, Phillips, Fordham, Bertranou, & Hale, 2012) .

These two uses, (rather than the various *types*), of modelling in particular are of central interest here. These modelling formalizations for the above two purposes differ from more traditional statistical modelling methods that are most familiar to those in the health and the social sciences. For instance, statistical analysis can be applied to longitudinal data in public health studies, but that longitudinal data is limited to representing that given phenomenon in one moment in time on a given timeline, presenting a more “static”, rather than dynamic, picture of phenomena. As the processes and populations that concern public health policymakers are by nature dynamic, (for instance, an epidemic of disease), a modelling tool that allows us to explore interactions between variables in real time is desirable in a policy setting (Gilbert, Nigel, Troitzsch, & Klaus, 2005).

Due to this capacity for capturing complex and dynamic systems phenomena, modelling in evidence-based public health policymaking is usually performed to ensure better characterisation of social or disease-spread phenomena (understanding or exploring) or for prediction, when trying to understand the impact of a policy decision on a given population in the future or for planning a response to something like a pandemic event (Gilbert, 2004). On a practical level, modelling methods are increasingly employed in public health policymaking not only due to their ability to capture complex systems dynamics, but because they can be used in situations and environments where other forms of evidence-generation or exploration of outcomes is impossible due to resource or ethical limitations (Garnett, Cousens, Hallett, Steketee, & Walker, 2011).

However, modelling for policy purposes can potentially become a complicated, costly, and time-consuming endeavour in itself. Models are often developed incrementally using iterative processes, and can go through numerous repetitions of various design phases, translating the assumptions of the model into code, and attempting to validate the model with empirical data (Garnett et al., 2011). Various types of models can have a wide range of computational and data capacity requirements, and policymakers and stakeholders who are non-expert in modelling methods may be unaware of, or unequipped to address, the processes entailed in the use of these models. Conversely, expert researchers and modellers may be unprepared to construct models under the pressures and constraints of a policymaking environment (Desouza & Yuan, 2013). As subsequent iterations of the model are developed, various scenario possibilities and parameter values may need to be adjusted, explored to account for scientific, social, or economic uncertainty, various stakeholder perspectives, or emerging data (Bilcke, Beutels, Brisson, & Jit, 2011), and this can take a considerable amount of time that policymakers and researchers may not have.

Although modelling plays a central role in the formulation of evidence-based public health policy, like all forms of scientific evidence in policymaking, evidence from models is subject to interpretation by both the modeller and the policymaker, and this can create further ambiguities or uncertainty in the final decision making process. Because of their dynamic, flexible nature and these layers of stakeholder interpretation, models may be used to justify a political agenda or decision, rather than being used analytically as is appropriate (Naess, Polack, & Chinsinga, 2011). One way to potentially offset some of these challenges is to encourage better communication and understanding between the model developer or researcher and the model user or policymaker, toward the end of developing a common nomenclature and shared situational orientation among both groups, so that the potential pitfalls of competing aims and multiple interpretations can be somewhat mitigated (te Brömmelstroet & Bertolini, 2008).

Despite these challenges, modelling for policymaking has particular strengths. This is especially the case for large-scale infectious disease projects, such as exploring the epidemiological dynamics of pandemic disease and the impact of behavioural interventions, or exploring the possible outcomes of immunisation policies. Dynamic, computational simulation models designed to explore disease transmission have significantly furthered the human understanding of biological transmission mechanisms, human response to risk communication, and the spatial features of infection during pandemic and epidemic events.

Moreover, computational modelling can assist in the study of potential policy solutions and guide their design, and potential impact (Desouza & Yuan, 2013). Desouza & Yuan (2013) also note how computational modelling allows policy stakeholders to anticipate the potential for unintended consequences of policy choices, and can assist in building consensus and communication amongst policymakers and researchers around a given policy problem. Because of the exceptional potential of modelling as a primary tool in policymaking, it is critical that we continue to foster its meaningful and optimal use, and to improve confidence in model-based conclusions. In order to accomplish this, it is necessary to gain a more sophisticated understanding of how modelling functions within the public health policymaking infrastructure, and to assess how model assumptions, parameters, and interpretations influence and impact on policy decisions (Samsuzzoha, Singh, & Lucy, 2013).

1.4 Research Questions and Study Descriptions

As previously discussed in this section, there are several factors that come into consideration in order to determine if public health policies that are underpinned by modelling methodology will be effective. There is the question of the quality of the scientific modelling, and whether it has been done correctly and the output is being interpreted correctly, whether those outputs are being integrated into the decision-making process optimally. Additionally there is the matter of public confidence and how the use of modelling is perceived from outside of the policymaking process, and to what extent public confidence in modelling methods play in their projected behaviour change. In consideration of the above landscape, several critical research questions arise. In this section, these questions are detailed, and the methods and approaches used in this work to address them are discussed.

Research Questions	Details and Chapter
How does disease severity and non-pharmaceutical intervention affect epidemiological dynamics?	Questions of how onward transmission and clinical severity are related are explored in Model 1 of Chapter 2, followed by an exploration of whether hand hygiene has an impact on epidemiological dynamics of note to pandemic planning efforts
How Does the Use of Contemporary Modelling Tools to Produce Public Health Policy Influence the Public's Projected Health Behaviour?	Data is presented in Chapter 3 that explores what members of the public think scientists might mean when they talk about "models", what methodologies constitute "good science" and how their perceptions of different forms of scientific evidence might influence how they would change their behaviour as recommended in policies surrounding pandemic disease and climate change.
What is the Nature of the Relationship of Policy Stakeholders to these Modelling Methods and how are they Employed?	A framework analysis is presented in Chapter 4 that explores how policymakers are using various forms of modelling and evidence to inform modelling in a real-time policymaking scenario. The challenges and processes surrounding the use of modelling in the policymaking environment are detailed and explored, with recommendations for new approaches.

Table 1-1: Guide to Research Questions and Chapter Content

1.5 Modelling Infectious Disease for Pandemic Planning: How does disease severity and non-pharmaceutical intervention affect epidemiological dynamics?

Often, successful policy in public health requires some response or change in behaviour from the public. Advanced public health policy practice thus requires an understanding of human psychology and health behaviour change, in order to predict and assess the impact that policies and risk communication that recommend behaviour change have on population health. Given the aforementioned ascendancy of modelling methods in the public health policy realm, the initial question that emerges at this juncture of policy and human behaviour pertains to the applied use of modelling methods to address a fundamental and pressing problem in public health policy: when we recommend a health behaviour in policy, such as handwashing during a pandemic, does that behaviour have an effect on epidemiological dynamics? Whether or not the public adopts a behaviour that could limit transmission, and whether that behaviour is actually effective in preventing disease, could have a profound impact on pandemic policies in several areas, including how we communicate about risk and how we plan for patient care during a pandemic event.

Epidemic models are particularly well-suited to address epidemiological, economic, and behavioural questions that public health policymakers are typically confronted with during outbreaks of disease (Fenichel et al., 2011). Pandemics of influenza in particular can have extensive and grave consequences, and because of their potential to quickly overwhelm even a prepared public health system, and the extensive modelling literature surrounding these viral pathogens, it provides an ideal scenario for a case study for the modelling exercises in Chapter 2.

In 1918, an influenza pandemic caused staggering mortality, killing an estimated 20 to 40 million people (N. Cox, 2003). To put this in perspective, the 1918 “Spanish” flu pandemic killed more people in 24 weeks than the HIV/AIDS pandemic killed in 24 years. Influenza pandemics have regularly occurred during the 20th and 21st centuries and the latest pandemics occurred in 1918–9, 1957–8, 1968–9 (N. J. Cox & Subbarao, 1999) and again in 2009-10. Since the 1918 influenza pandemic, global society has undergone significant social and ecologic changes that profoundly influence how a pandemic disease such as influenza is transmitted and controlled. These factors include exponentially increasing human population, and resulting close living proximity, rapid global transit by air and high-speed train, and larger populations of domesticated livestock that increase the likelihood of the types of human-animal interactions that could assist in the transmission of zoonotic organisms (Davey, 2007).

Beyond the possibility of devastating outbreaks of influenza caused by known pathogenic subtypes, there are emerging strains of influenza, the clinical and epidemiological characteristics of which are yet incompletely characterised, which pose a consistent threat to the health of the global human population. For instance, avian influenza strain, A (H5N1), caused a pandemic in domestic poultry and wild birds in 2003 affecting most of the world’s poultry population, as well as resulting in over 300 laboratory-confirmed human cases with a 60% case fatality ratio (Davey, 2007). While avian A (H5N1) influenza is not currently understood to be easily transmitted to humans or to cause widespread disease, whether or not an emerging zoonotic influenza pathogen such as this is likely to cause significant morbidity and mortality in the future is difficult to predict. Thus, understanding how to employ the best available technology in pandemic planning and mitigation efforts is of paramount importance.

More traditional scientific methods such as empirical or field studies that might be used to assess appropriate mitigation strategies to control influenza pandemics are “generally either infeasible (e.g. controlling movement of people within a city) or unethical (e.g. withholding vaccination of subpopulations to assess the effect on transmission)” (Carrasco et al., 2013, p.1). These more familiar methods may also have additional limitations, such as cost or other operational resource deficits. Therefore, computational epidemiological modelling is a highly suitable methodology that allows policymakers to explore the impact of various hypothetical pandemic preparedness or mitigation strategies.

Due to their suitability for this purpose, there has been a prodigious increase in the number of influenza pandemic models in the last decade, particularly since the H1N1/A pandemic of 2009, and many of these models are increasingly sophisticated, employing new and emerging parameterization and validation techniques, economic analyses (such as QALY), and information on the behaviour of individuals (Carrasco et al., 2013). Human health behaviour in response to infection risk is quite complex, and understanding this behaviour in the context of a pandemic of influenza is a fundamental task for researchers and policymakers alike. The primary question that the original modelling research presented in Chapter 2 addresses is one of how to most effectively explore the interactions of these risk-response behaviours in conjunction with the complex infection transmission dynamics typically found in these epidemiological pandemic events.

Contemporary approaches to influenza transmission mitigation often focus on changing individual behaviour, primarily through the recommendation of specific actions that are communicated to the public through a variety of means. Health promotion initiatives such as advertising campaigns, immunisation programmes that provide prophylactics like influenza vaccination, and formal policy recommendations from governmental and advisory health bodies have all primarily relied on public buy-in and compliance for their success.

How the public understands their risk of infection and how they change their behaviour accordingly is of fundamental importance in mitigating the effects of a pandemic, and having data on this public behavioural response during times of pandemic influenza threat provides a valuable contribution to the deliberations of policymakers and other public health stakeholders when they design interventions and make recommendations (Jones & Salathé, 2009b).

Behaviour change in the general population as a response to the threat of disease has been explored in the literature, particularly in the context of sexually transmitted diseases, but more contemporary work has sought to explore whether the lessons from the sexual health literature can be translated to other infectious disease threats that are emerging, such as pandemic influenza, and whether those threat-behaviour relationships are consistent across disease scenarios (Jones & Salathé, 2009b).

How and when the data on public perception of risk during influenza pandemics is collected can have an impact on the quality of research conducted, as the data is rarely available to interested researchers in real time, and self-report from the public on their behaviours and their perceptions is time-sensitive (Jones & Salathé, 2009b). Because the communication of effective early intervention strategies is the most desirable course of action for public health policymakers, having information on the public perception of disease threat and their willingness to behaviour change is especially valuable (Jones & Salathé, 2009b).

Many, if not most, influenza pandemic models rely solely on parameters from previous modelling studies, despite the availability of data external to other modelling-oriented studies, and those models are rarely validated using observed data about transmission dynamics as they might be mediated by human behaviour change as it is recommended in public policies (Carrasco et al., 2013). It is a characteristic of the modelling literature that it tends towards self-reference, and researchers in this area don’t often seek out information from non-modelling studies to inform their modelling exercises. Given the enormous impact that public health measures can have in mitigating the impacts of pandemics, Chapter 2 seeks to correct this feedback loop of self-reference in the modelling literature by informing models using data and information from a wide variety of clinical and psycho-social literatures.

I present a modelling exercise that explores H1N1A influenza disease transmission by utilising data from the clinical and experimental, rather than the modelling, literature. The same approach is taken in the second modelling exercise in Chapter 2, by integrating the transmission information from the initial model in the chapter with psycho-social and experimental data related to personal risk mitigation behaviours (in this case, hand washing), that are actually prescribed by public health risk communication and public health policy entities during pandemic events.

In order for epidemic models to become optimally predictive, and of greatest use to policymakers attempting to alter the course of an influenza pandemic, ensuring the model is accurately capturing "real-life" epidemic dynamics as represented in the clinical, behaviour-change, and scientific literature is of central importance, and every effort should be made to adjust the parameters of the model from available scientific data (Daley, Gani, & Gani, 2001). In Chapter 2, gaps in the literature surrounding the use of data on both transmission and transmission-disruptive behaviour change are therefore addressed.

1.6 How Does the Use of Contemporary Modelling Tools to Produce Public Health Policy Influence the Public's Projected Health Behaviour?

Modelling methods are being increasingly employed to inform policies and programmes aimed at coping with, and planning for, pandemic infectious diseases (Riley, 2007). Modelling methods can be used to inform action in an increasingly wide range of scenarios, from the surveillance of disease risk in large-group gatherings (Khan et al., 2012) to understanding the effects of global travel on disease dynamics (Balcan et al., 2010).

However, this increase in use isn't necessarily domain specific. In addition to the their use in pandemic disease policymaking, modelling methods have also become the most frequently used method in impact assessments surrounding another pressing public health concern: climate change (Feenstra, Burton, Smith, & Tol, 1998). Yet, despite their widespread use to address myriad issues of public health interest, these methods are often unfamiliar to individuals outside of public health research and policy environments where they are frequently employed. Indeed, Pidgeon & Fischhoff (2011, p246) point out that the scientific modelling underpinning policy that recommends public behaviour change can be unfamiliar, confusing, and unclear to lay people.

It is therefore critical to understand the relationship between modelling methodology and the potential for successful public engagement with health and climate change policy built on findings that rely on modelling. Specifically, the success of policies is mediated, in part, by responses to them by non-expert citizens. In order for policies to be successful, public support is required for two main reasons: politically because it allows politicians to propose them without jeopardizing future votes; and additionally in the case of policies that require individual level behaviour change as individuals and communities must be both willing and able to make the recommended changes in their behaviour outlined in the policy.

It is known that a range of individual, cultural, environmental and psychosocial factors influence behaviour change. Centrally important among these are the effects of health behaviour change and risk communication efforts, including the content, quality, and source of those messages and the manner in which they are delivered (Skinner, Campbell, Rimer, Curry, & Prochaska, 1999). It follows then that population and individual responses to policies that require the public to change their behaviour are likely to be mediated, at least in part, by the public's perceptions of the quality of the evidence on which those communications are based. More specifically, willingness among the public to engage in recommended behaviour change is expected to be linked to their confidence in the methods (content) used to generate the science that underpins the recommendations.

There are several different ways in which the public unfamiliarity or confusion around modelling methods may exert an undesirable effect on the public's willingness to undertake recommended behaviour changes in the face of a potential health threat.
The public may directly avoid uncertainty in health information, and may also manipulate uncertainty to their needs. For instance, health information (regardless of source) may be avoided primarily to limit feeling anxiety or fear; thus, if there is public sentiment that data from a particular methodology may be inaccurate or unreliable because that methodology is unfamiliar, this can contribute to the public justifying such avoidance, leading to the rejection of behaviour changes as per policy recommendations (Sairanen, Savolainen, & Anu Sairanen, 2010). In fact, when people do not understand the basis for proposed policies, or when the best available science conflicts with "common sense" suggested by their existing cognition about what constitutes reliable evidence, the public are unlikely to adopt appropriate policies or generate political support for legislation to implement them (Sterman & Sweeney, 2007).

In order to address this issue of public confidence in modelling methods and whether the public is willing to change their behaviour based on policies underpinned by modelling methods, Chapter 3 presents findings from a study employing quantitative (survey data) and qualitative (semi-structured brief interview) methods to ascertain: (1) the levels of confidence among the public in scientific predictions on the basis of the scientific methodologies used; (2) public opinion regarding the level of confidence required of scientific predictions before they are used to inform mitigation policies; (3) the forms of evidence that would convince individuals that particular actions would be effective in mitigating harm from pandemic influenza and climate change; (4) public knowledge of current modelling methodologies. A fundamental understanding of the relationship between public knowledge and confidence in science is necessary not only in the case of whether the public will successfully adopt mitigation policies, but in the context of what is known to researchers and policymakers about public understanding of methods and how that understanding might affect a wide range of public health behaviours.

Modelling methodology has given the scientific and policy community an unprecedented tool with which to predict events and behaviours, and to explore their resulting impact. However, the development of sophisticated interventions and policies from modelling tools to address intractable social issues such as climate change and pandemic disease is not sufficient to ensure positive outcomes. A detailed understanding of the relationship between the public perception of recommendations, public confidence in scientific methods, risk communication, and behaviour change is necessary if we wish to persuade the public to support sustainable action. The data in Chapter 3 seeks to address these issues.

1.7 What is the Nature of the Relationship of Policy Stakeholders to these Modelling Methods and how are they Employed?

In an evidence-based policy environment, it would be ideal for policymakers and policy stakeholders to have consistent access to a systemised process by which they evaluated evidence and considered the interaction of multiple variables in the complex social systems of their concern. Desouza & Yuan (2013) argue that computational modelling in particular shows promise toward fulfilling that ideal by providing an environment capable of "capturing, synthesizing, visualizing, and interpreting massive amounts of information across a wide spectrum of forms, functions, and origins" (p16). In fact, a vast array of computational models with various aims, levels of utility, and structures are indeed currently in use in the public health policymaking environment (V. J. Lee, Lye, & Wilder-Smith, 2009). Yet, despite the growing ubiquity of modelling in the policymaking community, there are many challenges for the policymaker in utilising these modelling tools to optimal effect.

One critical challenge surrounding the increased use of modelling in policy is the modelling-specific knowledge base of the policymakers that are using models to underpin policy decisions. Because modelling, and indeed systems thinking, are emerging ideas and methods in the realm of public health, policymakers and involved policy stakeholders who have received training in more traditional public health methodologies and approaches are unlikely to have extensive training in modelling methods, and modelling for policy is not currently widely featured in public health curricula or training (Luke & Stamatakis, 2012).

Additional challenges for policymakers using modelling methodologies as decision making tools can arise from the collaborative process of working with researchers who are, in fact, expert modellers. For instance, the primary aim of modellers working on public health problems may be to gain mathematical information that may help answer questions pertaining to the mechanisms of disease transmission, while public health policymakers might require different metrics on pandemic severity: information that augments planning and capacity efforts (Arino et al., 2011). Policymakers and modellers may face competing political considerations, time constraints, and operational and budgetary deficits, all issues that can present roadblocks to the successful use of modelling methods to inform public policies (Arino et al., 2011).

However, despite these challenges being fairly well-characterised in the literature, there is little evidence in the modelling literature to suggest that inroads have been made into understanding the process of modelling use in public health policy settings, with Desouza & Yuan (2013) calling for research on how modelling-generated evidence and outcomes might influence policy decisions and how policy makers perceive, and interact with, modelling methods in the policymaking setting. It is in consideration of this critical gap in the literature that Chapter 4 of this thesis employs cutting-edge qualitative methodology to more fully examine how modelling methods are used to make critical public health decisions about immunisation programmes, and how policymakers and models function together in an applied situation.

In Chapter 4, the deliberations of a major governmental advisory committee are presented and analysed using Framework Analysis, an emerging qualitative method that is becoming increasingly central to health services research. The discussions of the committee as they use multiple forms of evidence (including QALY and other modelling methods) in the service of determining whether or not to approve a new vaccine for inclusion into the adolescent and infant immunisation schedule are examined to more completely characterise the various interactions and tensions that arise as they make this high-impact decision.

However, this exercise was not solely undertaken in order to characterise the tensions of actual real-time model use to make public health policy decisions. It is imperative that all of this information is synthesized with a view toward developing recommendations that can help policymakers anticipate, and thus develop strategies to mitigate, some of the difficulties they might face when using modelling in the course of their duties. Some suggestions for these strategies are outlined in the 5th and final chapter of this thesis.

Ultimately, advanced decision-making tools like models that can synthesise and analyse complex, multivariate datasets have almost unlimited potential to assist policy stakeholders in making the best evidence-informed decisions for human health. And although this process is often fraught with difficulty and partial understanding, the best avenue for a truly optimised modelling-policy interface is the continued interdisciplinary exploration of the relationship between the two. This thesis contributes to this most important endeavour.

Chapter 2 - Modelling Infectious Disease for Pandemic Planning: How does disease severity and non-pharmaceutical intervention affect epidemiological dynamics?

2.1 Influenza as a Pathogen, Risk from Pandemic Influenza, and Pandemic Planning

Pandemic Influenza (PI) has caused substantial morbidity and mortality in the 20th century, and has also caused significant economic and social disruption. Prior to the H1N1 pandemic of 2009, three major pandemics in the last century have been identified: the 1918 Spanish flu, 1957 Asian flu, and the 1968 Hong Kong flu. Of these, the 1918 pandemic causing the greatest mortality; an estimated 30–50 million deaths worldwide (Horimoto & Kawaoka, 2005). Influenza viruses are classified into three types (influenza A, B and C), and of these, influenza A causes the most clinical interest and is the most clinically significant pathogen (Julkunen et al., 2000). Influenza virus type A draws such interest due to its unique epidemiological, ecological, and evolutionary features: it is found in a wide variety of bird and mammal species capable of transmitting the virus to man, and the primary timescales of its specific disease dynamics are unique, with pandemic and viral evolution being happening at roughly the same time (Earn, Dushoff, & Levin, 2002).

Influenza A is highly contagious and has been related to a large array of symptoms and complications in human hosts. Influenza A infection maybe clinically characterized by fever, sore throat, headache, chills, myalgia and accompanying cough with associated general symptoms such as appetite loss, malaise and vomiting (N. J. Cox & Subbarao, 1999). While influenza A infection is often uncomplicated and self-limiting, some individuals may experience additional symptoms and develop severe, even life-threatening, complications. Children are particularly susceptible to complications from influenza A infection, and often suffer from otitis media, conjunctivitis, pharyngitis, sputum production and more severe upper respiratory tract symptoms such as croup during the acute phase of the infection (Julkunen et al., 2000).

Primary viral pneumonia is the most severe complication from influenza A infection, and can develop quickly, from within 1‑2 days from initial influenza infection. It may result in respiratory failure and death (N. J. Cox & Subbarao, 1999). Cox & Subbarao (2009) also note that patients who have chronic diseases or are immune compromised have a greater risk of secondary bacterial and viral infection, and they also have a greater risk of other complications. Bacterial pneumonia, which usually starts several days after onset of influenza symptoms, is associated with *Streptococcus pneumoniae*, *Staphylococcus aureus*, *Haemophilus influenzae* or group A β-hemolytic streptococci (Barker, 1982).

Influenza viruses are enveloped, negative-stranded RNA viruses, belonging to the family *Orthomyxoviridae*. Influenza H1N1A is of most recent pandemic interest, and the various viral "types" in influenza stem from the proteins encoded on the viral RNA. Influenza A virus RNA is composed of eight segmented genes, which encode for ten different proteins (Lamb & Krug, 1996). Viruses with HA protein types H1, H2 and H3 and NA types N1 and N2 are pathogenic in humans. The main antigenic determinants of influenza A and B viruses are the haemagglutinin (H or HA) and neuraminidase (N or NA) transmembrane glycoproteins. Based on the antigenicity of these glycoproteins, influenza A viruses are further subdivided into sixteen H (H1.H16) and nine N (N1.N9) subtypes. While the virus is capable of replicating in a variety of hosts across species, in human hosts, influenza viruses replicate in the epithelial cell layers of the upper respiratory tract preferentially, but also can replicate in other cells, specifically macrophages and other leukocytes (Zeng et al., 2013).

Planning for pandemic influenza has raised questions regarding the origin of these novel influenza viruses, and has prompted much research and speculation, a current popular theory being the re-assortment of completely novel virus from both avian and human sources, but no precise origin has yet been identified (Potter, 2001). There is increasing empirical evidence that suggests that these influenza viruses are assisted in their spread by the increasing ease, speed, and accessibility of global travel (Brownstein, Wolfe, & Mandl, 2006). It is reasonable to conclude that as transmission is assisted by an increasingly connected global community, the efforts to mitigate risk and limit transmission will also have to be increasingly global.

Influenza pandemics occur due to the introduction of novel subtypes of influenza A into an immunologically naïve population, and it is this immunological naivety that facilitates the rapid, and often devastating, spread of influenza across the globe (Potter, 2001). Pandemics of novel influenza A viruses are caused by either, 1) *antigenic drift* from previous strains of virus, in which case exposure to previous but similar mutants of the influenza virus may have conferred some partial, immunity to a host population as the virus has changed only slightly, or 2) *antigenic shift* from previous viral strains¸ in which the virus is completely novel, and no host population has had any previous exposure with and thus has no immunity (Potter, 2001). The 20th century alone has seen multiple pandemic influenza outbreaks, and this is likely to be an issue we will have to cope with continually throughout the next century. Planning efforts should focus on lessons learned in containing or mitigating previous pandemics, and creating policies that rely increasingly on evidence and best practices, such as ensuring the organizational structure is in place that would support successful epidemiological surveillance and can administer the appropriate infection control interventions (Godfrey & Schouten, 2014).

Because the necessary biological information needed to cope with antigenic shift or drift in a novel virus may not be immediately unavailable, thus restricting the ample time needed to develop biologically-based prophylaxis like vaccine, it becomes necessary to attend to pandemic planning with a focus on non-pharmaceutical and behavioural interventions (NPI) to mitigate risk from pandemic influenza and to formulate public policy. In lieu of biological interventions for pandemic influenza, the alternative route to managing a pandemic emergency may employ NPI as a cost-effective way to mitigate the harms of a pandemic influenza outbreak by reducing host-to-host transmission (Wu, Riley, Fraser, & Leung, 2006). Pandemic planning using behavioural interventions, and a detailed understanding of human behaviour in the face of infectious disease risk, will become particularly useful in times of global economic austerity and in resource-scarce areas, or areas where the distribution of mass prophylaxis in the form of anti-viral medication or vaccine is not feasible.

Pandemic planning for influenza is also highly transferrable. Information and evidence gathered during pandemic planning research and practice could potentially be used to cope with a variety of other global threats and emergencies, including those from bioterrorist activities (Cox, 2003). Yet, in spite of the overall usefulness of pandemic planning, and the high risk of morbidity and mortality posed by novel pandemic influenza pathogens, less than 30 countries worldwide have pandemic plans, and even fewer have policies or actionable protocols on how to deal with pandemic influenza when it occurs (Cox, 2003). In light of this, pandemic planning is not only a challenge to the global scientific community and policy stakeholders in public health, but an ethical imperative to gather and disseminate the best practices and knowledge globally and rapidly. Swift, coordinated global effort alone will allow public health scientists and officials to cope effectively with the serious threats to economic and social stability caused by future novel pandemic influenza.

Attempting to cope with influenza pandemics post-hoc instead of effective planning, pre-emption, and communication is likely to be ineffective, as once a pandemic event begins, its rapid spread is likely to exceed the speed with which we can respond effectively (Cox, 2003). Global capacity for pandemic preparedness has not yet reached its full potential, and remains a critical policy issue worthy of time, academic resources, governmental involvement, and economic support. It also requires that we use the best tools and best practices available, and this in turn requires interdisciplinary communication and collaboration, employing the functional, applied use of emerging tools for prediction and policy.

2.2 Pandemic Planning, Models, and Prediction

Davey, (2007) notes that planning, as opposed to post-hoc management, is essential for reducing or slowing transmission of a pandemic influenza event and for decreasing the number of cases, hospitalisations and deaths over time in order to effectively cope with the capacity limitations of healthcare delivery systems and limit overall morbidity and mortality. Pandemic plans and policies allow policy stakeholders and healthcare workers to maintain essential services and to mitigate the economic and social impact of an influenza pandemic. Pandemic influenza has the greatest impact on the poorest countries and communities, as a result of limited surveillance, healthcare resources, limited numbers of healthcare workers, and generally poor baseline health and nutritional status of underserved and impoverished populations (Uscher-Pines, Duggan, Garron, Karron, & Faden, 2007).

Pandemic planning also requires a significant amount of political and social capital. Political support and commitment at the highest levels is often necessary to develop effective pandemic influenza preparedness plans. Inter- and intra- national and regional collaborations are not only critical for the creation and execution of pandemic preparedness plans, but are instrumental in lobbying for international support and resource allocation for these endeavours by pooling resources and increased power of advocacy by acting collectively (Stohr, 2003).

Planning for pandemic influenza also necessitates effective and targeted information and communication from public entities such as health boards, health departments, research institutions, and other emergency response organizations. Communicating risk is critical both before, and during, a pandemic event. Pandemic plans should take a global perspective, and should always include a strategy for appropriate risk communication that is flexible enough to target a variety of populations across the global geographic area, and will be effective through the duration of a pandemic influenza event (Reynolds & Quinn Crouse, 2008).

Planning for pandemic influenza presents numerous challenges not only to the scientist, but for the large array of policy stakeholders and practitioners who would rely on scientific findings to create effective and feasible mitigation, prevention, and control plans. In order to plan, it is critical to be able to predict the epidemiological patterns of pandemic influenza, and anticipate the effectiveness of interventions ranging from vaccines, anti-viral medications, and NPI's such as behavioural change, and travel restrictions. Using computational and mathematical modelling to this end is an effective way to inform polices and assist in making the necessary predictions to do so (Smith, 2006). Computational modelling specifically allows us to use powerful assistive technologies, such as sophisticated temporal and spatial visualizations, to inform planning policies in a way previously impossible. Utilizing these powerful tools in policy development should be a primary aim in the future.

However, modelling is not without its own set of challenges in assisting with the prediction needed to formulate pandemic influenza planning policy. Models, by nature, are approximations, so they are necessarily operating under assumptions and also may be informed by incomplete or partial information (Smith, 2006). They also need to be tested against, (or include information from), experimental and observational studies. Despite these challenges, models have been used successfully to direct and create effective mitigation policies in coping with other serious public health threats, such as the 2001 Foot and Mouth Disease outbreak in the United Kingdom that utilized mathematical modelling (Ferguson, Donnelly, & Anderson, 2001).

In the context of pandemic planning, modelling is often informed by real data gathered in context. Smith (2006) argues that, "experimental epidemiological studies, such as the vaccination of school children or those that follow family units, provide core information for model design and parameterization, and (especially if there are multiple independent studies) for model testing." Using existing information to underpin model formulation can assist in reducing the challenges created by mere assumption, thus allowing us to parameterise models in a wider array of scenarios, ranging from the impact of interventions to improved epidemiological surveillance.

Modelling for policy in pandemic planning is becoming the subject of increasing interest and review since the most recent pandemic influenza outbreak of H1N1a in 2009 (Coburn, Wagner, & Blower, 2009). Both medical and behavioural interventions have been modelled thus far, using relatively simple variations of the Susceptible-Infectious-Recovered (SIR) model of influenza transmission, and the SIR model is also used in the context of simulation frameworks and projects (Coburn et al., 2009). The modelling of pandemic influenza scenarios has generally been considered a successful endeavour that has contributed to human knowledge of the spatial-temporal dynamics of pandemic influenza transmission (Coburn et al., 2009).

Modelling pandemic influenza has greatly increased the human understanding of epidemiological dynamics in a manner pertinent to pandemic planning. One study compared the severity of seasonal influenza epidemics in the US, France, and Australia over the past three decades by estimating country-specific values of R0 (Chowell, Miller, & Viboud, 2008), demonstrating that epidemic severity in the three countries is similar every year, but year to year is highly variable. There have also been modelling studies that have been done to determine what effects various mitigation interventions may have had on disease dynamics in historical outbreaks. Bootsma & Ferguson (2007) estimated that public health measures such as social distancing reduced influenza mortality by 10 to 30% in US cities, suggesting that the timing of public health interventions can have a strong influence on pandemic influenza peaks.

Models can also provide a platform for experimentation and data generation on broad scale, and for a greater diversity of interventions than is possible with other methods. Modelling methods for pandemic events have fewer ethical implications than experimental designs, and are optimal tools for examining complex scenarios with multiple interventions or behavioural variables that are beyond the scope of more traditional public health designs. These properties inherent to models therefore suggest that they could be a valuable tool for the creation and implementation of effective interventions and policies for the control and prevention of pandemic events.

However, most studies have focused on behaviour as it pertains to influenza transmission in a context largely limited to travel behaviours or mass isolation protocols, for instance, the effectiveness of quarantine (Coburn et al., 2009). Since models are able to accommodate parameters that approximate multiple interventions or behaviours toward the aim of prediction and informing planning policy, it is desirable that we would use models to also explore the full-range of behavioural and NPI's. As our knowledge about the cost-effectiveness and efficacy of different kinds of NPI's and behavioural change in pandemic influenza becomes more complex and sophisticated, so can we build models that reflect this level of complexity and sophistication.

Vespignani, (2009) states, "If fed with the right data, computational modelling approaches can provide the requested level of predictability in very complex settings" (p.425). One of the current challenges to using modelling specifically for pandemic influenza planning is the relatively limited knowledge of human behaviour in the face of pandemic influenza threat, and the lack of longitudinal and comprehensive quantitative data about behaviour change or public perception of risk from pandemic influenza on a global scale (Vespignani, 2009). However, Vespignani continues, "In recent years, however, tremendous progress has been made in data gathering, the development of new informatics tools, and increases in computational power" (p.425). Harnessing that increase in computational power to explore the full range of data available about behavioural change and the efficacy of NPI's, such as hand hygiene, could provide information that would allow scientists and stakeholders to finally optimize the global capacity for pandemic preparedness.

Research conducted during and after the H1N1a 2009 pandemic provided major gains in these critical areas of behavioural inquiry that Vespignani (2009) identifies. It is this combination of increasing knowledge in the area of human behaviour change in pandemic scenarios, better understanding of the public perception of risk, and the knowledge of what behaviours people will adopt, and when and why they adopt them, that present a compelling opportunity to use modelling methodology to explore the impact of these previously oblique, but fundamental, variables in the pandemic influenza planning effort. The timely modelling of these behaviours, and integration of these findings in synthesis with virological, clinical, and epidemiological, information, is necessary to plan for pandemic influenza effectively, is thus the primary purpose of this inquiry.

2.3 Modelling Behaviour Using H1N1a 2009: Needs and Challenges

There is already varied use of computational models in the literature that explore the impact of human behaviour and NPI's for the purpose of pandemic planning. However, Smith's review (2006) of the use of modelling for pandemic influenza planning reveals that a majority of the scientific inquiry that attempts to model behaviour pertaining to pandemic influenza focuses on slightly modifying relatively simple SIR models, and large-scale NPI’s such as quarantine and behaviours pertaining to global human travel patterns. For instance, some models have explored the effect of “one-off “community interventions (Milne, Kelso, Kelly, Huband, & McVernon, 2008), which focus primarily on social distancing measures such as school closure, increased case isolation, workplace non-attendance, and community contact reduction.

Other more computationally powerful, larger-scale global models have also been developed and used with success toward informing pandemic planning as it pertains to global social travel and more complex population mixing behaviour that would impact transmission and epidemiological dynamics of a novel influenza pathogen. The Global Epidemic and Mobility (GLEaM) model employs a structured metapopulation approach to the stochastic modelling of disease dynamics, using high resolution census data worldwide and human mobility patterns at the global scale (Balcan et al., 2010). GLEaM has already been used to successfully simulate pandemic conditions using real data available from previous outbreaks of novel pathogens, notably H1N1 (Balcan et al., 2010). A modelling platform like GLEaM has enormous potential to inform policy by exploring more complex transmission-inhibiting behaviour and the effects of risk perception in a meaningful way, and has shown promise, through its accessible client-server interface, to assist a variety of policy and scientific stakeholders that are non-expert modellers in developing more sophisticated global policies that address the threat of pandemic influenza.

The H1N1a 2009 influenza pandemic prompted research which gave additional information on human behaviour, risk perception, and NPI’s which was previously lacking, and have been identified as necessary areas of exploration for pandemic planning using modelling methods (Vespignani, 2009). The rich and current data surrounding H1N1a 2009 makes it an ideal pathogen to use for enriching pandemic planning globally, and for integrating the fundamental behavioural, intervention, virological, medical, and epidemiological information toward the aim of planning. It will thus be used throughout this chapter as our primary pathogen of inquiry. However, the research surrounding H1N1a 2009 is far from complete or straightforward, and it requires attention to detail and an approach that focuses on synthesizing a wide array of information from various disciplines.

While the importance of modelling behaviour has been introduced above, in this chapter, human behaviour and perception of risk in an H1N1a 2009 pandemic planning scenario is explored for the following reasons: 1) Behavioural interventions and NPI’s are typically more cost-effective and accessible than biomedical interventions in the event of a pandemic, and how these behavioural interventions are perceived is likely to predict whether they will actually be adopted, 2) Information about risk perception, behavioural interventions, and NPI's has increased since the 2009 pandemic and has remained relatively unexplored with modelling methodology, and 3) There is a lack of information that successfully integrates and synthesises the clinical, behavioural, epidemiological, virological, and outcome-based evidence toward the aim of pandemic planning.

This chapter also identifies challenges to this endeavour as well as fulfilling the needs identified above, and identifying these needs and challenges is the result of intensive interdisciplinary collaboration between international institutions. In order to study the impact of behaviour change on pandemic influenza transmission in a meaningful way, it is necessary to understand several variables.

First, it is important to understand how influenza virus is spread. The question of onward transmission of influenza through either aerosolized routes or droplet/contact routes will be discussed in detail in this chapter. Secondly, it is important to understand how the different routes of transmission affect the severity of clinical illness, and that will follow the discussion about transmission in this chapter. Third, it is important to understand the literature surrounding behaviour change during the course of an influenza pandemic, and the literature is reviewed regarding what is known about that behavioural change in an infectious disease threat scenario. Data in the literature regarding the use and effectiveness of NPI's and behavioural changes, focusing on hand hygiene, will then be discussed. Finally, we will detail our efforts at successfully modelling this behaviour and the findings and implications that came from those efforts.

We have met with some success in understanding how influenza may be transmitted, and what behavioural changes occur during a pandemic. However, it has been difficult to assess what the various routes of transmission have to do with the severity of disease in clinical cases. This would obviously have an effect on the epidemiological profile of any pathogen, and is critical information if we wish to use modelling methods to predict or plan for any number of epidemic or pandemic scenarios.

In order to appropriately approximate severity in our model, it is important to understand how severity is defined and understood in the literature, if at all. There seems to be no unifying protocol on how to classify severity of disease in the epidemiological, intervention, or virological literature. However, the clinical literature surrounding the diagnosis and patient care of H1N1 and other influenza infections has yielded a somewhat clearer picture.

At the end of this chapter, the implications for pandemic influenza planning policy of our modelling efforts, and the challenges and gaps in the relevant literatures, will be summarized and discussed. We will also identify future directions for research and inquiry that pertains to planning policy.

2.4 The Transmission of Influenza and the Role of Influenza Severity

In order to effectively model complex risk-response behaviours, or to explore in a model the impact on the outcome of different forms of NPI's such as hand-hygiene or mask wearing have on onward transmission, it is important to explore the literature surrounding influenza viruses and their transmission. It is also important to characterize the clinical symptoms of influenza infection that are likely to be epidemiologically relevant to onward transmission in order to identify NPI's and behavioural change approximations in a model that are most likely to disrupt the transmission process.

In this section, the transmission of influenza as a pathogen, human immunological response to influenza, and the development of clinical symptoms from infection are discussed. To this end, the virological, clinical, and medical literature will be used to present evidence from human experimental and natural setting studies, immunological response studies, animal experimental studies, and human NPI studies. Subsection 2.5 provides characterization of what is generally known about how influenza is transmitted, to how it causes an immune response in the human host systemically and at the site of infection, and how that leads to the development of characteristic symptoms. In the following subsection 2.6, the characterization of the severity of those clinical symptoms, and symptom severity's impact on onward transmission, will be explained. Then the selection of cough as a critical clinical symptom in the onward transmission of influenza, and its use as an approximation for severity in a modelling scenario, is discussed.

2.5 Influenza Transmission and Symptom Development

Brankston, Gitterman, Hirji, Lemieux, & Gardam, (2007) distinguish between four routes of transmission for influenza-like illnesses: direct contact, indirect contact, large droplet, and aerosolized airborne transmission. According to Brankston and colleagues (2007), these routes of transmission are defined as follows. Firstly, *indirect contact* occurs by passive transfer via an intermediate object such as the hands of a care worker that are contaminated and not washed between patients, or contaminated instruments or other inanimate objects in an individual's immediate environment. Secondly, *direct contact* occurs when transfer results from direct physical contact between an infected or colonized individual and a susceptible host (including skin contact through shaking hands, etc.). Thirdly, transmission via *large droplets* is described as being due to droplets generated from the respiratory tract of an infected individual during coughing or sneezing, talking, or during procedures such as suctioning or bronchoscopy. Large droplets are defined as those that travel less than 1m through the air and are deposited on the nasal or oral mucosa of the new host or in their immediate environment, and do not remain suspended in the air. Finally, *aerosolised airborne* transmission refers to the spread of microorganisms contained in droplet nuclei (airborne particles less than 5 μm) or in dust particles containing skin squamous cells and other debris that remain suspended in the air for long periods of time. Brankston et al., (2007) argues that since 99.9% of droplets resulting from natural coughing have sizes greater than 8μm, small droplets form primarily through the evaporation of large droplets.

Tellier, (2009) considers an alternate range of transmission routes for influenza. He suggests that there are three main routes of transmission for influenza: 1) aerosol, 2) large droplet transmission, and 3) self-inoculation. Aerosolised transmission depends on particles that are sufficiently small enough to remain suspended in the air for prolonged periods due to their diameter and low settling velocity. Large droplet transmission relies on infectious particles that enter the body via intranasal inoculation. He also explains that higher doses are required for infection in the case of large droplet transmission, compared with small droplets. Transmission in the third category is described as being due to "self-inoculation of the nasal mucosa via contaminated hands" (pS783).

Natural, tidal breathing also appears to generate a large proportion (over 87%) of droplets in an infected individual, some of these droplets as small as 1 μm in diameter, indicating yet another potential source of influenza transmission (Fabian et al., 2008). These smaller droplets may remain suspended in the air, and are prone to wide dispersion by air currents, the result of this being that they can be inhaled by susceptible hosts some distance away from their point of origin (Fabian et al., 2008). There is also evidence to suggest that there are other factors that might influence the viability of H1N1a p09 and other influenza viruses in the process of transmission. Some current research has been focusing on the air quality factors that might best facilitate aerosolized influenza spread, for instance (Yang et al., 2009).

Tellier (2009) also summarises evidence in this area to conclude that ‘there is considerable support in the scientific literature for a contribution of aerosol transmission to the spread of influenza A. These include “prolonged persistence of infectivity in aerosolized influenza A virus at low humidity, the transmission to volunteers of influenza by aerosols, reproducing the full spectrum of disease, at doses much smaller than the doses required by intranasal drop inoculation (which mimics large droplet transmission), and the interruption of transmission of influenza by blocking the aerosol route through UV irradiation of upper room air” (p.S783).

However, both of these categorisations present difficulties. Firstly, whilst Brankston’s categories overlap, Tellier’s fail to capture a range of possible transmission scenarios, thus neither represents a true taxonomy. For instance, Brankston (2007) notes that indirect contact occurs when the host is infected by coming into contact with the virus in the environment. However, the definition of droplet transmission includes the possibility of deposition of particles in the environment, which must then be acquired by the susceptible individual, thus implying indirect contact. On the other hand, Tellier’s reference to self-inoculation via infected hands appears to ignore the role of other fomites in transmission processes.

The transmission of influenza in volunteers during experimental study suggests that bronchial inhalation of small droplets is more likely to cause infection in comparison to inoculation by large droplets into the upper respiratory tract or conjunctival membranes (Alford, Kasel, Gerone, & Knight, 1966; Bridges, Kuehnert, & Hall, 2003). The problem of lack of definitional clarity in these characterizations means that it is difficult to draw scientific conclusions from existing research on most likely routes of transmission, especially in natural settings. Furthermore, neither classification of infection mechanisms lends itself easily to parameterization in a model, as it becomes difficult to understand what NPI or behaviour would disrupt transmission when transmission is not clearly defined in the literature. However, understanding the immunological response to influenza can assist in understanding how symptoms develop after infection occurs, and therefore, how symptom presentations in individual clinical cases might impact on onward transmission to susceptible hosts.

When influenza A enters a susceptible host, it does so through the through the respiratory tract. In the human lung there are about 300 million aveoli, or sacs, that function by exchanging inhaled gases to oxygen and transporting it to the bloodstream. The typical rate of ventilation in humans at rest is approximately 6 liters of air per minute, but even at rest, this can introduce large numbers of foreign particles into the lungs, including aerosolized droplets containing influenza virus into the lungs (Baigent & McCauley, 2003). Where those viral particles deposit in the respiratory tract depends on their size, as smaller droplets with a diameter of approximately 1 to 4 µm will likely deposit in the small airways, but larger particles are either not able to enter the respiratory system or are deposited in the upper respiratory tract (Biagent & McCauley, 2003).

Biagent & McCauley (2003) explain that the entire human respiratory tract is covered with mucus-secreting cells and glands covered in cilia, or small hairs. Any foreign bodies that end up in the nasal or upper respiratory tract are captured in this mucus and transported to the back of the throat where they are then swallowed, but in the lower respiratory tract are brought up by the movement of the cilia of epithelial cells. In sacs that lack cilia or mucus, macrophages are responsible for destroying particles. The main target for infection by influenza viruses are the upper and lower respiratory tract epithelial cells and this is also where the virus replicates. Once the virus has successfully infected these epithelial cells, replication of the virus occurs rapidly, and although the initial infection occurs in the respiratory tract, it can cause more general systemic symptoms.

Cytokine response at the site of infection, specifically in the respiratory tract, causes inflammation at the site, and the bronchial system overreacts, the production of mucous can increase, and the small airways can become partially obstructed (Utell et al., 2015). The cytokines release hormones into the immune system which trigger the hypothalamus to cause fever as a general immune response to infection. The viral replication of an influenza infection in the respiratory tract then begins to cause cell damage and cell death via apoptosis (Oslund & Baumgarth, 2011).

In general, the inflammation from the immune response to influenza causes irritation and reactivity at the site of deposition of virus, usually in the respiratory tract. The release of cytokines and hormones from the rapid replication of the virus and the apoptosis of damaged cells are related to more general immune response systemically. It is now necessary to characterize the clinical symptoms of influenza A infection as they arise from these immune responses.

According to Lessler et al., (2009) incubation period of influenza is relatively brief, ranging from 1-2 days. The onset of the disease is usually sudden and has systemic symptoms such as high fever and chills, severe malaise, extreme fatigue, weakness, headache and myalgia, as well more localized respiratory symptoms arising from hyper-reactivity from inflammation at the site of infection, such as non-productive cough, sore throat, and rhinitis.

Fever ≥ 37.8°C	68
Feverishness**	90
Cough	93
Nasal congestion	91
Weakness	94
Loss of appetite	92
Sore throat	84
Headache	91
Myalgia	94

*In 2,470 patients with laboratory-confirmed influenza

Table 1-2. Above is from data provided in Monto, Gravenstein, Elliott, Colopy, & Schweinle, (2000) characterising the proportions of patients presenting with a range of symptoms after lab confirmed influenza diagnosis.

The most common symptoms in laboratory confirmed influenza A infection in Monto, Gravenstein, Elliott, Colopy, & Schweinle, (2000) are fever at about 37.8C, with elevated temperature below that classified as “feverishness”, and cough, occurring in 93% of patients. In this study, fever and cough were the most frequently observed clinical symptoms in laboratory-confirmed influenza A infection.

Adults infected with the influenza virus may be infectious from as early as 24 hours before the onset of symptoms until about seven days after symptoms subside, but immunocompromised patients might shed influenza virus for weeks, or even months (Klimov et al., 1995). In general, the clinical course of influenza infection may be mediated by the patient's age, the degree of pre-existing immunity, properties of the virus, smoking, co-morbidities, immunosuppression, and pregnancy (Nicholson, Wood, & Zambon, 2003).

However, the clinical progression of pandemic influenza is not always a straightforward matter, and in conjunction with the difficulties presented by inconsistent characterization of basic transmission, can complicate efforts to build and parameterize models that will accurately predict the effect of interventions and behaviour changes in a way useful to policymakers. In subsection 2.6., the challenges of fully characterizing the role of transmission, symptom severity, and the impact of severity on onward transmission will be discussed.

2.6 Symptom Severity and Onward Transmission

There remains some contention in the literature regarding the strength of the evidence regarding transmission mechanisms and how to appropriately characterize the clinical features of influenza infection related to these routes of transmission (Vukotich, 2010). There are, however, consistencies in the findings that warrant consideration in the context of a model that could be used to inform policy. Thus far, the route of transmission, source of infection, and their relationship to clinical outcomes have not previously been related in the modelling literature.

In the following subsections, the following will be discussed: 1) The connection between the route of transmission and the presence of cough in severe disease 2) Animal models, human experimental, and human observational studies that link severe infection with increased viral shedding 3) Implications of severity for onward transmission of influenza infection, and 4) The characterization of cough as an appropriate approximation for severity in our modelling endeavours. The challenges and gaps in the transmission literature that were encountered will also be addressed before discussion of modelling severity begins.

2.7 Animal Models

The experimental animal model literature predominately uses ferrets, and the studies pertaining to influenza offer some useful data regarding the relationship between route of transmission and symptom severity. The ferret has been extensively used for studying various aspects of human influenza viral infection, its clinical course, and results of various routes of infection. The ferret is so extensively used as a model translatable to human influenza infection for the following reasons, 1) Influenza infection in the ferret closely resembles that in humans with respect to clinical signs, pathogenesis, and immunity; 2) Types A and B of human influenza virus naturally infect the ferret, thus providing an opportunity to study a completely controlled population in which to observe the interplay of transmission of infection, illness, and sequence variation of amino acids in the glycoproteins of the influenza virus; and 3) The ferret has other physical characteristics that make it an ideal model for deciphering the manifestations of the disease (Herlocher et al., 2001).

The clinical signs of influenza infection in humans and ferrets are very similar, and disease in ferrets is mediated by similar factors, the age of the host, the strain of the virus, environmental conditions, and the degree of secondary bacterial infection (Herlocher et al., 2001). Ferrets tend to show similar disease patterns to humans that are infected with the same type A strains, commonly characterised by rhinitis that progresses to tracheobronchitis marked by cough (Renegar, 1992). Areosol droplets are the primary mode of transmission in ferrets (Renegar, 1992; Herlocher, 2001), and the resulting course of clinical illness of the influenza virus in ferrets is very similar to that observed in humans (Herlocher, 2001; Matsuoka, Lamirande, & Subbarao, 2009).

Notably, in the ferret model, there is a fairly clear relationship between the route of transmission of the influenza virus and the resulting disease due to the immune responses of the animals. When ferrets are experimentally inoculated intranasally with larger droplets, local replication of the virus in the upper airways occurs and, as discussed earlier, only rarely progresses to severe disease, but particularly virulent strains of influenza A are also capable of infecting the lower respiratory tract and causing cough and tracheobronchitis, however both ferrets and humans most prominently feature mild disease in the upper airways, where no bronchial activity would be evident (Herlocher, 2001). As with humans, when lower respiratory deposition occurs, it is likely to result in reactivity of the airway and cough, whereas infection primarily in the nasal cavity affects primarily that area. Increase in cough due to lower bronchial infection is likely to generate more aerosols that would more readily be inhaled deeply into the lower respiratory tract of a susceptible host.

Bodewes et al., (2011) present findings that confirm the notion that the route of transmission has a relationship with the resulting pathogenesis of influenza infection in ferret models, noting that intratracheal (inhalation) inoculation of ferrets with the same virus reproducibly “caused severe bronchointerstitial pneumonia”. They continue by noting the route of inoculation is important for primary disease presentation. The method of virus inoculation requires careful consideration in the design of ferret experiments as a model for influenza A/H5N1 in humans. Bronchial involvement here would also be reasonably assumed to cause cough and airway reactivity in the human in the case of inhalation of influenza particles into the lower respiratory tract. Hinds (1999) notes that in humans, aerosol particles ≤5 μm are capable of reaching deep into the respiratory tract and being deposited in alveolar tissues.

Further, there is evidence that areosolation and the inhalation of the aerosol particles that deep into the bronchi can be confirmed in ferret models with the deposition patterns of influenza virus following inoculation not been previously in ferrets, but that fluorescent-labeled influenza virus, when administered using our aerosol system, is deposited in the upper and lower regions of the ferret respiratory tract (Gustin et al., 2011). Gustin et al. (2011) directly addresses the issue of route of transmission and how it relates to clinical disease by explaining that although the relative importance of different routes of transmission used by influenza A viruses remains controversial, it is likely that the modes of transmission are not mutually exclusive, and, whether transmission occurs at close range or long range, aerosols are likely to be involved.

2.8 Human Experimental and Observational Studies

In human studies, the characterization of severity and the relationship of clinical disease to onward transmission or route of infection is not straightforward. Classification and discussion of severity in the literature is not marked by the same kind of standardization in protocol than the more controlled experimental studies involving ferrets. However, there are still notable areas of scientific consensus that can be successfully used to identify cough as a marker of severity and to provide useful parameterizations for a modelling study that could be used to inform policy.

Alford (1966) demonstrates the possibility of transmission via small, aerosolized droplets and larger droplets implicated in contact transmission. However, the issue of the relative importance of these routes in natural settings is largely unresolved (Hall, Douglas, Geiman, & Meagher, 1979). Previously discussed findings have suggested that onward transmission may also be affected by other factors than clinical symptoms generating droplets or aerosols. These previously discussed studies noted that an immunocompromised patient might shed virus for months, even after initial symptoms of infection have waned. Indeed, Hall (1979) found that more severely infected patients demonstrated higher shedding of viral load. There is additional information that supports the notion that severe disease is associated with longer duration of symptoms and higher viral shedding counts, which would logically create a greater opportunity for the onward transmission of influenza.

For example, a review by Carrat et al., (2008) showed that viral shedding, as measured by quantity of viral particles, tracked symptom score over time. Furthermore, more severe symptoms were shown to be associated with increased quantity and duration of viral shedding. In H3N2, there was a positive correlation in two studies between viral shedding (measured using nasal washes) and symptom severity (Carrat et al., 2008). Finally, respiratory symptoms resolved more slowly than systemic symptoms (Carrat et al., 2008).

Further evidence for the relationship between more severe forms of disease and higher viral shedding, as well as longer duration of clinical symptoms can be found in three other studies. Firstly, Hall et al. (1979)'s paediatric study demonstrated that more severe illness was associated with greater viral shedding. Zambon, (2001) showed that cases with a larger number of positive test results also demonstrated longer recovery times and longer duration of cough symptoms among untreated (placebo) individuals. Finally, To et al., (2010) examined 74 cases admitted to hospital, focusing on severe cases of lab-confirmed H1N1 2009 during May-September 2009. These were categorised into three groups of inpatients with ARDS (Acute Respiratory Distress Syndrome) and immune response was measured via tests of cytokine activation while viral shedding was measured as viral load in sputum and endotracheal aspirates (aerosols). The two categories of severe disease had a high viral load for a longer period than those with less severe disease. Theoretically, more severe illness, which is more likely to be due to airborne transmission, should lead to the observation of increased R_0 values, due to the longer duration and increased transmissibility of infection, which has clear implications for infection control.

Understanding severity in the clinical setting presents some challenges, however. Hoeven et al., (2007) and Cunha (2008) caution that infection control for influenza should be based on laboratory findings during the diagnostic process and not from the presence or absence of clinical symptoms. They cite the difficulty in clinical diagnosis for those who are mildly to moderately ill, and the difficulties of making accurate differential diagnoses. Discerning the clinical presentation of mild to moderate influenza from other clinically similar illnesses, such as "influenza-like" illnesses (ILIs) caused by parainfluenza virus, respiratory syncytial virus (RSV), adenovirus, etc., is difficult as there is no clear clinical differentiation (Cunha, 2008). However, while this is an important note of caution, mild or moderate influenza is less likely to involve the lower bronchial tract, and therefore less likely to involve cough, which is the clinical symptom of our primary interest to use as an approximation of severity for a modelling exercise.

Cunha (2008) states that diagnosing severe influenza A may present a different scenario than that of the relatively undifferentiated mild/moderate influenza due to the presence of "characteristic clinical features which have diagnostic specificity (p. 92)." Cunha (2008) also notes that severe influenza is usually diagnosed through "A weighted point system…The point system is based on a weighted selected clinical/laboratory finding given different point scores. This suggests that it is a combination of lab findings and symptoms that are used in a clinical setting to diagnose severe influenza", Cunha continues, "Isolated clinical/laboratory features have little diagnostic specificity, but by combining characteristic findings the diagnostic specificity of clinical/laboratory signs is enhanced. Our point system is designed to clinically identify severe influenza A, but is not useful to diagnose mild/moderate influenza A or B."

Pertaining to the presence of cough in H1N1a specifically, Rello et al.,(2009) present findings from a review of the clinical literature that implicates cough as present during severe influenza, but not necessarily as a symptom indicative of severity. Rello also gives indication that severe influenza has a distinctive feature in prolonged viral shedding, even with anti-viral treatment in the clinical setting, "A common report is of a prolonged time to negative virus excretion associated with the need for higher oseltamivir dosing and longer duration of treatment than standard therapy (75 mg orally twice a day) (Rello et al., 2009)." Increased or prolonged viral shedding in those with more severe disease would certainly have implications in the community setting for onward transmission, even after the severe patient has been hospitalized.

In Rello et al., (2009) severe H1N1 infection is also associated with the development of pneumonia, specifically secondary bacterial pneumonia, "Primary viral pneumonia was defined in patients presenting during the acute phase of influenza virus illness with acute respiratory distress and unequivocal alveolar opacification involving two or more lobes with negative respiratory and blood bacterial cultures. Secondary bacterial pneumonia was considered in patients with confirmation of influenza virus infection that showed recurrence of fever, increase in cough and production of purulent sputum plus positive bacterial respiratory or blood cultures."

The increase in cough in severe influenza would logically increase the likelihood of onward transmission by increasing both droplet and aerosol generation, and the respiratory distress may also increase droplet transmission during tidal breathing. Previous evidence during sections characterizing influenza have demonstrated that secondary pneumonia is common in severe forms of influenza, and here it is explicitly detailed that those who were eventually diagnosed with the pneumonia after a primary diagnosis of H1N1 was made exhibited increased or marked cough.

While laboratory testing to confirm severe influenza is desirable, it is not always feasible. This is particularly the case in low-resource or underserved settings, and thus a necessary consideration for a policy-building exercise. In the absence of laboratory tests, clinical diagnosis of influenza takes the form of an assessment of a range of symptoms. Ebell, Lundgren, & Youngpairoj (2013) reviewed the existing clinical decision rules for influenza diagnosis, synthesising these for the purpose of formalisation within their paper. According to their procedure, each of nine symptoms is rated on a 4-point scale of severity (0=none; 1=mild; 2=moderate; 3=severe). The symptom set considered includes headache, sore throat, feverishness, myalgia, cough, nasal symptoms, weakness, and loss of appetite. In addition to individual symptom severity ratings, an overall illness score is also calculated as the sum of individual ratings.

Clinical presentation can be used in comparison with laboratory findings to paint a precise picture of severe influenza infection. Zambon (2001) used a similar scale to compare the clinical diagnosis of community cases of influenza with various laboratory diagnostic techniques and found that the total symptom scores at baseline showed significantly greater severity of symptoms and an increased number of positive laboratory test results. This work demonstrates that there are biomarkers of more and less severe cases and that severity can be measured objectively. There is other evidence from the analysis of the most severe cases - those leading to death – that points to particular symptom clusters associated with severe forms. Shieh et al., (2010) report on a histopathological study of patients who had died from confirmed 2009 H1N1. Among these patients, cough was the second-most prevalent symptom (67%; following fever at 82%) for those individuals for whom symptom data were available. The third most prevalent symptom was shortness of breath (58%).

Specifically in relation to cough symptoms, Cao et al., (2009) show that existence and duration of cough predict for longer duration of viral shedding (in a logistic regression testing viral shedding for less than or greater than 5 days) and indeed that cough is the most informative clinical symptom for the duration of viral shedding. Little, Gordon, Hall, & Roth (1979) also demonstrate cough persisting for less than 7 days in all five experimentally inoculated participants, while all those in the natural infection class experienced cough for greater than 7 days. In summary, more severe forms of disease are associated with higher viral shedding and longer disease duration, especially cough resolution. These characteristics indicate increased opportunities for onward transmission among severe cases, both through longer shedding periods and quantity of virus shed into the environment.

In summary, route of infection, via airborne or contact modes, has important implications for the symptom set of individuals and this in turn impacts onward transmission. There is a higher probability of persistent cough and respiratory problems as symptoms of severe forms of disease, and severe disease is associated with infectious viral load and probability of shedding virus for prolonged periods. Taken into consideration collectively, the epidemiological implications are fairly clear.

Overall, following from the data above, these simplifications can be made: A) There are two forms of disease, mild and severe, characterised respectively by lack or presence of cough due to inflammation of the lower respiratory tract (B) Severe cases are caused by airborne transmission and the deposition of aerosolised droplets in the lower bronchial tract, whereas mild cases result from direct and indirect contact and cause mostly rhinorrea and upper respiratory discomfort and (C) severe disease is associated with overall higher probability of onward transmission, and especially, a higher probability of secondary cases generated by the airborne route.

With these assumptions established, subsection 2.9 focuses on the construction of a model accounting for different routes of transmission and analyses of this model.

2.9 Modelling Severe and Mild Disease

This section focuses on the construction of a model that is appropriately parameterised using the information above, and the results of that modelling endeavour. Understanding how clinical severity and onward transmission interact and affect epidemiological dynamics is a key question for pandemic planning, and the chosen outcome indictors of this exercise in the section below speak directly to the type of information that policymakers and pandemic planners find necessary to create appropriate preparedness initiatives. More generally, using this type of modelling in a non-expert scenario in order to generate policy-relevant epidemiological information provides some insight into the necessary processes and challenges policymakers face in using modelling methods to underpin preparedness policies. Subsection 2.10 will discuss the parameterization and structure of the model, Subsection 2.11 will discuss the results generated from the modelling exercise.

2.10 Model Structure and Parameters

Key outcome measures of interest were selected according to their importance for public health and pandemic planning, with each indicator providing critical information for policymakers and planners on how many affected people they can expect to see, how many people with severe cases they can expect to see, and thus, how much treatment or prophylactic capacity to plan for. They are as follows: (A) Total number of cases over course of epidemic; (B) Total number of severe cases over course of epidemic; (C) epidemic peak time; and (D) Number of cases (severe, mild, and total) at peak.

The main structural differences between this model and a typical S-E-I-R model are that there are two infectious compartments to reflect to the two forms of infection: Infectious (Mild), I_M, and Infectious (Severe), I_S, and two exposed compartments Exposed (Mild), E_M and Exposed (Severe), E_S to distinguish between individuals who have come into effective contact with infectious cases of the two forms. The rates of transition between exposed and infectious forms are dependent on numbers in the exposed compartment with exposure to mild disease leading to less likelihood of causing severe infection; recovery rates also differ between forms of the disease. The model is as follows:

$$\frac{dS}{dt} = -\beta_S I_S S - \beta_M I_M S$$

$$\frac{dE_M}{dt} = \beta_M I_M S - \sigma E_M$$

$$\frac{dE_S}{dt} = \beta_S I_S S - \sigma E_S$$

$$\frac{dI_M}{dt} = P_M \sigma E_M + (1 - P_S)\sigma E_S - \gamma_M I_M$$

$$\frac{dI_S}{dt} = P_S \sigma E_S + (1 - P_M)\sigma E_M - \gamma_S I_S$$

$$\frac{dR}{dt} = \gamma_M I_M + \gamma_S I_S$$

Structure of the Model

In the model above, the transmission terms, β_S and β_M, are for severe and mild conditions respectively, and determine the effective contact rate for both forms of disease. Once exposed, the rate at which the exposed individuals in the model become infective is denoted by σ. E_M and E_S denote individuals who have been exposed to disease and whether this exposure was via contact with a mild or severe case. P_M And P_S are the probabilities that an individual develop mild symptoms or severe symptoms. So, for example, P_M is the probability that an individual who has contracted disease from a mild case goes on to develop mild symptoms, and the same rule applies to the severe condition. Finally, γ, the rate of recovery from either mild or severe disease, is the final term in the mild-severe model.

Solving the Model

The epidemiological model was translated into code and run in R, which has several options for ordinary differential equation solvers that give highly accurate solutions and that automatically alert users to errors. The numerical differential equation solver package used was a standard one for solving this kind of model, called the deSolve package.

Parameters of the Model

The literature was examined to find parameter estimates for the terms in the model, and Table 2 below summarises these parameter estimates and their sources. After the table, more detailed explanations from the literature are provided for the following values in the model: σ (latency periods until symptoms), γ (recovery rates) and the transition probabilities

Term in Model	Parameter Value and Source of Parameter Choice
Individuals in model	N=999
$\boldsymbol{\beta_S}$ **and** $\boldsymbol{\beta_M}$	β_M at 0.0004 per day and β_S at 0.0008 day, from Carrat, et al, (2008)
$\boldsymbol{\sigma}$	0.5, from Carrat et al., (2008); Cao et al., (2009); Lessler et al.,(2009) and Cowling et al.,(2009)
$\boldsymbol{\gamma}$	Mild: 1/ γ_M= 5 days and Severe: 1/ γ_S = 7 days, from Carrat et al., (2008) and Cao et al., (2009)
$\mathbf{P_S}$ **and** $\mathbf{P_m}$	Probability (P_S) from exposed severe to infectious severe (E_S, I_S)=0.8 Probability (P_m) from exposed mild to infectious mild (E_m, I_m)=0.79 from Carrat et al., (2008); Cao et al,. (2009); Lessler et al., (2009); and Little et al., (2009).
Days	The time period in the Mild-Severe model

Table 2-2. Parameter Values

The latency period: 1/ σ *:*

There was no evidence in the literature that the latency period (1/ σ), varies between mild and severe forms of disease. In their review of nasal inoculation studies, and Carrat et al. (2008) reported two mean latency periods from among the studies considered as mean time from infection to onset of symptoms of 1.7 days and 2 days. These values fall within the range found in natural infection studies: Cao et al. (2009) found a median of 2 (range :1-7); Lessler et al., (2009) found a mean of 1.4 days; in Cowling et al., (2009) a mean incubation time of 1.5-2 days. Therefore, I use the same value of sigma for both mild and severe forms of infection, choosing 1/ σ = 2.

The recovery time: 1/ γ:

The estimates for recovery times (period from onset to resolution of symptoms) are based on Cao et al. (2009) and Carrat et al. (2008). Specifically, using resolution of cough symptoms as a marker, selecting the upper bound of the inter-quartile range (IQR) for the duration of cough symptoms of those experiencing cough for >5 days versus <5 days, as an estimate of resolution time for severe and mild respectively, giving $1/\gamma_M = 5$ and $1/\gamma_S = 7$ (Cao et al., 2009). The upper bound of the IQR was chosen rather than the median as the values reported for the duration of cough are likely to represent underestimates. Specifically, I note that 351 of 426 participants were treated with antivirals, 254 of whom within 48 hours of the onset of symptoms, while antivirals administered within 48 hours were associated with reduced infectious periods. The data that directly measured shedding times was also considered. On the basis of their review of experimental intranasal inoculation studies Carrat et al. (2008) provide a potential estimate of $1/\gamma_M = 4.8$ (range is 1-8 days). This may be an overestimate of recovery time among mild cases, since 21% of participants did have a cough (Carrat et al., 2008), known to be associated with longer durations of viral shedding (e.g. Cao et al., 2009).

Transition Probabilities:

In estimating the transitions (P_M, P_S) between exposed and infectious compartments, I use data from Carrat et al. (2008) for transitions from those exposed to mild cases by equating nasopharyngeal inoculation with exposure to a mild case without a cough. In this study, exposed participants had a cough (severe) with probability 0.21 (i.e. of developing severe disease (I_s) from exposure to mild disease, P_M); correspondingly, 0.79 had no cough, which means that mild disease exposure results in mild disease infection.

For transitions from E_S to I_s Cao et al. (2009) was employed as a basis for parameter values, as this work related to natural infections and no large-scale experiment involving aerosol inoculation has been conducted. This study was useful as it minimised the usual difficulties of underreporting of cases that occurs in most studies of natural settings. Cao et al. (2009) report a prevalence of cough of 69%; however, this is likely to be an under-estimate given that a large proportion of cases (254 of 426) were treated with antivirals within 48 hours of the onset of symptoms. Nonetheless, the fact that only 20% of cases that arise from intranasal inoculation (mild) lead to cough symptoms (severe) suggests that this underestimate is likely to be minimal. The suggestion that 0.69 represents an underestimate in our model is consistent with higher cough prevalence in other natural acquisition studies: Lessler et al. (2009) reports cough in 90% of cases, Little et al. (1979) in 100% of cases, although these studies suffer from issues of underreporting. As a compromise between these values, 0.8 was used as an approximation for the transition probability (P_S) from exposed severe to infectious severe (E_S, I_S).

2.11 Findings from the Model and Implications

As stated previously, outcome measures of interest for this model were selected according to their importance for public health and pandemic planning, and the findings are presented in order for each of these key indicators:

(A) *What is the total number of cases over course of epidemic*? The total number of cases at the end of the epidemic was 989 out of 999 individuals in the model, leading to a 98% rate of seropositivity at the end of the epidemic, a fairly high rate which was not unexpected, but could still place a significant burden on health systems overall: from general practitioners seeing an influx of more mild disease, to more urgent care settings and hospitals dealing with severe cough, but with most people ill to some degree in our susceptible population.

(B) *What are the total number of severe cases over course of epidemic?* One of the key factors in effective pandemic planning is the ability to anticipate the number, or proportion, of cases you may encounter that are most likely to tax the resources available. These cases that are most likely to result in complicated mortality or even increased morbidity are those that feature more severe clinical symptoms, as characterised in this model by cough. 29% of total cases in this modelling scenario are mild cases, with 71% of total cases presenting with severe disease. This means that 71% of infected individuals in this scenario are likely to present with cough. Although the clinical significance of severe symptoms including cough will vary between and within populations, such a large proportion of people with severe symptoms could have notable capacity and planning implications for a healthcare system. Within both mild and severe conditions there are individuals that may not seek healthcare services (leading to an underestimation of both severe and mild cases, but mild cases particularly) and even some people with cough will have uncomplicated influenza that self-limits. Yet, the potential of coping with a large population of people with a severe symptom for which they may need extended healthcare services is a point of interest for the pandemic planner and policymaker. Understanding that there may be an underestimation of those who are actually infected with (and spreading) disease but may not necessarily all be seeking care also has implications for the control of disease and the understanding of epidemic dynamics, particularly in the case of influenza, where cases cannot be lab confirmed for epidemiological purposes if people infected are not seeking care.

The following findings, (C) *epidemic peak time*; and (D) *number of cases (severe, mild, total) at peak*, should be considered in conjunction, and in a fashion that compares mild and severe cases to fully contextualise the potential importance of these findings to pandemic planners. Please refer to Figure 1 below:

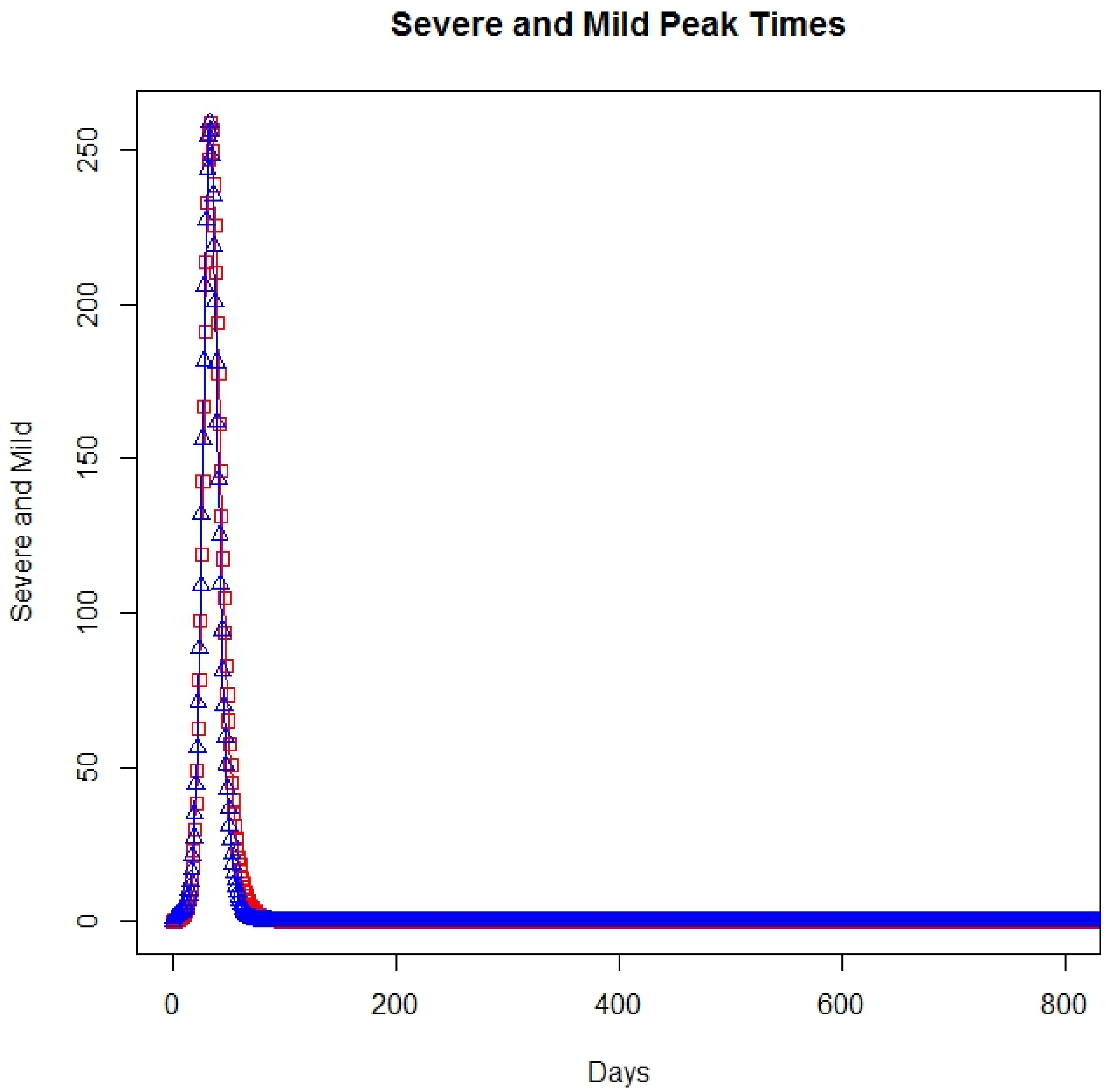

Figure 1-2. Severe and mild peak influenza times

Overall, mild disease (in blue) and severe disease (in red) peak at the same time, and there are a significant number of additional cases that the model predicted in the severe (with a ratio of 3 severe: 1.08 mild cases). This suggests several notable things about the epidemic dynamics. First, it suggests that the presence of proportionally more severe clinical symptoms doesn’t appear to have a significant effect on the overall epidemic peak time, although while the presence of severe disease is proportionally meaningful enough to have an effect on pandemic planning, severe disease as characterised by cough does not seem to follow a different epidemiological pattern than mild disease. Since cases of severe disease and mild disease peak at the same time, it is unlikely that the appearance mild disease will precede cases of severe disease, and thus the natural disease dynamics would unlikely to be useful as a kind of “early warning system” to planners and policymakers that multiple cases of severe disease were forthcoming.

In Chapter 5 broader implications of using information from models of this type are discussed in the context of pandemic planning and policymaking that seeks to mitigate the spread of infectious diseases like influenza. The processes of a non-expert modeller using this method to explore these questions and make predictions about possible scenario outcomes during and epidemic are also discussed.

Now that the implications of the Mild/Severe model have been explored, the following section will focus on understanding behaviour as it relates to pandemic disease threat, the public perception of risk, the communication of risk, and the adoption of non-pharmaceutical interventions for pandemic disease prevention. In the final modelling exercise, a new variable is introduced into the above model that allows us to explore whether these non-pharmaceutical interventions impact upon the outcome indicators I have explored here.

2.12 Human Behaviour Change, Public Risk Perception, Risk Communication & the Threat of Influenza Infection

This section will explore the findings from the psychological, communication, and public health literatures to establish a characterization of human behaviour change in the event of a pandemic disease scenario. Any sound planning policy will include detailed information on how to communicate effectively with a variety of diverse communities and groups in the event of a pandemic emergency. In Subsection 2.13, the public health, cognitive, health, and public health psychology literatures were reviewed in order to ascertain how people change their health behaviour in response to risk communication specific to infectious disease, why they change their behaviour, and to what extent this behaviour changes. Factors such as the nature of the communication, its source, and population and individual characteristics are also considered. Subsection 2.14 specifically examines behaviour change in response to H1N1 outlining both commonly changed behaviour and the demographic characteristics of those likely to exhibit behaviour change, although direct links between self-reported behaviour change and risk communication specific to H1N1are unclear.

2.13 What is Known About Behaviour Change In the Face of Risk

The ultimate goal of gathering data on infectious disease, either through real-time epidemiological surveillance or though model-based simulation of disease process, is the accurate planning, implementation, and evaluation of public health interventions, programs and communications (Heymann & Rodier, 2001; McQueen, 1999 ;Klaucke et al., 1988). However, in order for this surveillance or simulation to be of optimal utility, an understanding of health behaviour in response to these interventions, programs, and communications within and between populations is necessary (Veazie et al., 2001).

The demographic factors that influence health and risk behaviour in response to information regarding disease are multivariate and complex. It is key to note that both individual *and* social environmental factors influence what behaviours individuals change and to what extent (McLeroy, et al., 1988). The social ecological perspective (SEP), prevalent in both the public health and psychological literature, includes the notion that societal structures have mediating and moderating, in addition to direct, impacts on health behaviour, and that many of these factors will be specific to the population in question and the environment in which, and with which, they interact. The SEP was popularized by Bronfenbrenner's (1979) Ecological Systems Theory which identifies four levels of interaction: macro-, exo-, meso-, and micro-, each level describing influences as intercultural, community, organizational, and interpersonal or individual. Bronfenbrenner's perspective (1979) was founded on the internal characteristics of the person, the characteristics of the environment, and the continuous interaction of the individual with the environment. Bronfenbrenner argues that it is not solely the environment that directly affects an individual, but that there are mediators and moderators in between which may be multivariate and complex, all having impacts on the next level, with each echelon operating fully within the next larger sphere (Bronfenbrenner, 1979).

The influence of person characteristics beyond basic demographics on health behaviour is also of note, and the effects of variables such as age and gender are discussed further. Some of the more "complex variables", such as political orientation or values, have been examined in both public health and psychological forums.

Variables such as political ignorance or orientation, denial, obduracy, and cultural norms often compound the risk of infectious disease transmission in ways intractable to communication or education efforts (Albrecht, Fitzpatrick, & Scrimshaw, 2003). Further, standard public-health prevention theory has been based on the assumption that education leads to rational behaviour change. However, an approach focusing on education alone and on an expectation of individual behavioural responses to available information may not be appropriate in all circumstances, as the availability of educational information or materials does not always impact behaviour in expected or significant ways (Albrecht et al., 2003). This is important to note when examining patterns of disease transmission in specific populations, as the positive impact of efforts at risk communication may be mitigated by a cultural or political phenomena, and examination and post-hoc study or analysis of findings may become necessary to explore and explain these effects.

There is evidence that one of the most effective measures for stemming an outbreak of an infectious agent is to externally control behaviour between populations, such as closing major air travel hubs, restricting the range of infectious, or potentially infectious, individuals. However, these measures are often met with firm opposition due to the economic, social, and policy implications of mass restrictions, and are rarely implemented despite their effectiveness (McLean, May, Pattison, & Weiss, 2005). Any outbreak of a novel and little-understood infectious disease is likely to be characterized by high levels of public concern. Sandman, (2003) argues that people's willingness and ability to cope with risk, to bear anxiety, to follow instructions, to help their neighbours, and to return to baseline rates of health and behaviour when the crisis is over will all depend to a significant extent on the content of the risk communication in question, and the perceived severity of those contents by the target audience.

Despite the unwillingness of most individuals and populations to capitulate to mass travel restrictions or quarantines, and the public health community's caution in advocating these types of restrictions due to issues of panic and public backlash, it is possible to create positive health behaviour change in a variety of populations through effective health and health-related risk communication. For instance, The Health Education Authority for England's anti-smoking TV campaign was effective in reducing smoking prevalence through encouraging smokers to stop and helping prevent relapse in those who had already stopped (McVey, 2000).

Most people in the developed world get health information from two sources that can be considered “primary”: mass media and trusted sources within social networks, i.e., close friends and family, or trusted community leaders (Lunin, 1987). While the primacy of the mass media as the information source may be secondary in some cases to community contacts in the developing world, it still has major effect. Thus, it is important to understand how the media gets its information, and how it formulates messages about risk to the public. Journalists will use established or official sources for information that is used to create news articles or items (Lunin, 1987). These should be credible, available, and must be able to supply reliable information (Gandy, 1982). Sources may be established spokespersons for government agencies, businesses or other powerful groups and elites in the social system (Hilgartner & Bosk, 1988; Donohue, Donohue, Tichenor, & Olien, 1995). However, the media also serves as a translational entity, and how they choose to *frame* the information effects what the public believes to be fact and how they might change their behaviour in response to the risk (Makoul, 1991).

Meta-analysis of available data suggests public response to media communication of risk is dependent upon such social cognitive variables as source credibility, fear, organization of arguments, the role of group membership in resisting or accepting communication, and personality differences (Perloff, 2003). This points to behaviour change in response to risk as an effect of *persuasion* as opposed to the simple dissemination of factual information. It is again important to note that multiple studies confirm that public education is highly variable across populations, and the act of education alone does not guarantee health behaviour change. Studies show populations with higher educational levels are more likely to learn factual information about health and health risk than other populations (Hyman & Sheatsley, 1947). Therefore, merely increasing the flow of raw information is more likely to benefit or incite behaviour change in groups with higher educational levels than those from lower educational strata.

The media venue from which individuals and groups garner information about health (and all groups appear to have this interest), also has an effect. Those who glean information from print media are more knowledgeable than those who get their information primarily from other media sources, i.e. television (Finnegan &Viswanath, 1996). Greater availability of diverse sources of information, and access to primary care providers as a source of health information, may work to the advantage of residents of larger communities, such as urban areas (Viswanath & Finnegan, 1996). The internet, which has become central to any serious consideration of the function of risk and health communication in behaviour change, is quickly becoming the primary media outlet from which individuals and groups garner information on health and health-related risk. Rainie (2001) reports that 80 million Americans regularly access the internet to obtain medical and health information. This includes a substantially high number of African-Americans and senior citizens than would be expected given overall demographics. Yet, access to the internet and the availability of high quality, high speed networks across age, race, and SES is unequally distributed, although the gap is closing (Venkatesh & Brown, 2001).

The perception of the *amount* of risk a population is assuming bridges aforementioned variables of environment and individual characteristics, to an extent. People are more likely to change their health behaviours if the risk is perceived to be grave, and if this perception is supported by other members of their self-identified groups (there is public "outrage"). However, it is noteworthy that even if the perception of risk is grave, mass, externally applied amelioration efforts (such as enforced quarantine), are generally ill-received, whereas mass non-intrusive efforts (such as scanners at airports to detect elevated body temperature indicative of fever) care met with greater levels of compliance (Tan, Chlebicka, & Tan, 2010). This level of compliance is increased when examining strictly voluntary behaviours such as remaining home from work or public spaces when ill, if the individual perceives the threat as highly likely, highly dangerous, either, or both, and the risk outweighs the complexity level of the task the individual is being asked to perform (Demers & Viswanath, 1999). Bandura, who is the progenitor of the Social Cognitive learning theory now widely applied in public health settings, argues that it is the *complexity* of the behaviour change that dictates how likely an individual is to perform it (Bandura, 1994, 1998).

Yet, the ready availability of information, and the means and desire to access it, does not necessarily mean that the recipient of information will understand the information available. Nor is there assurance that even careful journalists using credible sources will accurately convey this information. However, it is possible to clarify some of the misinformation and confusion risks of using the media as the sole source of risk and health communication with the public. Targeted, culturally sensitive and audience appropriate health behaviour change campaigns direct from public health entities with established public presence have created desirable health outcomes effective across race, gender, and socioeconomic groups, but understanding the complex interaction of communication efforts at these intersectionalities is a continuing process (Williams, Mohammed, Leavell, & Collins, 2010).

In order to appropriately target audiences for competent communication, it is important to note that individual or group characteristics such as gender, age, race, or SES may still influence whether or not, or to what extent, communication about risk has an effect on behaviour. How people get health risk communication or what they are likely to do about it once the information has been received often relies on the message's ability to persuade the recipient to undergo health behaviour change.

The influence that individual characteristics can have on behaviour change is well documented. For instance, individual characteristics, such as sex and gender, have been explored in a variety of risk and health studies, but does not always serve as a modifier of behaviour or risk perception (Prochaska & Velicer, 1997). The *biological distinction of sex* exists as a variable in most epidemiological studies, but the cultural effect of gender construction and its influence on health and risk communication perception may be lacking. Understanding the effects of gender, not just sex, should be considered central to any epidemiological research endeavor to appropriately inform an epidemiological surveillance or simulation effort although gender may not have a sizeable effect in some circumstances, but it may in others. This is particularly true in pathogen-specific studies, for instance, those that examine the socio-psychological variable that influence HIV transmission. Yet, the findings on gender as a modifier are too complex to generalize.

However, there has been evidence that gender has a relatively weak effect on the likelihood of health behaviour change in the face of other infectious disease risk communication (such as those in influenza), "because of the absence of gender effects on health behaviour change, I conclude that health behaviour interventions do not need to be specifically tailored more for men or women; instead, health behaviour interventions can be similarly promoted across gender" (Prochaska & Velicer, 1997).

2.14 Behaviour Change and H1N1

The effects of demographic variables on health behaviour in the most recent pandemic influenza outbreak in 2009 are readily apparent. Older individuals are more likely to engage in behaviour that prevents poor health outcomes due to an increased perception of risk for morbidity and mortality consistent with their age cohort. However, the short-term changes in behaviour documented in response to infectious disease are not necessarily the same in long-term behaviour change related to lifestyle behaviours pertaining to chronic illness, such as in Pretchroska, In fact, health behaviours, disease development, and treatment outcomes can often be attributed, at least in part, to somewhat ineffable qualities; quality of life is impacted by work conditions, social connectedness, and community participation (von dem Knesebeck, Dragano, & Siegrist, 2005).

Rubin, Amlot, Page, & Wessely, (2009) found that women, people aged 18 to 24, and parents of young children were significantly more likely to follow recommended infection control behaviours during the most recent swine flu outbreak. Participants who were not employed, were poor, had an annual household income of less than £30,000, or had no educational qualifications were significantly more likely to adopt avoidance behaviours to change their infection risk. The largest effects were for participants from non-white ethnic backgrounds, who were significantly more likely than white participants to adopt both infection control (handwashing) and avoidance (staying home) behaviours (Rubin et al.,, 2009). This presents evidence for the *confluence* of personal characteristics (sex, age, income, education, and ethnicity) as important for what behaviours households report changing.

It is impossible to definitively state that anxiety generated by risk messaging specific to H1N1 leads to efficacious behaviour change to avoid infection (Rubin, 2009; Kasperson, et. al, 1988). However, when behaviour change to avoid infection from H1N1 was reported, increased hand-washing was most commonly cited as the most-frequently employed method of infection avoidance in both the US and the UK (Jones, 2009; Rubin, 2009) and is the most frequently recommended method of infection avoidance by the CDC (CDC, 2011). Hand-washing is also a more readily accepted method of infection avoidance for an H1N1 scenario than are other efficacious methods, such as vaccination. (Chor, et. al, 2009)

The findings of Jones (2009) are consistent with that of Rubin (2009); that in a large sample being female had a significant effect on increased hand-washing behaviour, however a potential criticism of both studies is that while they both have a large sample size, both sample populations skew toward the highly-educated and the evidence for hand-washing (as opposed to social avoidance) comes from these samples. However, that does not mitigate the extent to which hand-washing is advocated by the CDC across populations, therefore, there is ample evidence to argue for hand-washing as the most likely candidate for an infection control proxy in any computational model of infection processes.

Ibuka, et. al., (2010) also confirms the findings of Rubin (2009) and Jones (2009) in a large US sample that women are more likely change their behaviour to avoid infection than men, and that there is a temporal effect to behaviour change in response to H1N1; individuals are more likely to increase protective behaviour at the beginning of an outbreak when their perception of risk of infection is high, as opposed to as an H1N1 outbreak wanes. Ibuka (2010) also confirms that this phenomena across studies is consistent with the classic view of behaviour change in public health according to the Health Belief Model.

While no study made an effort to directly link the behaviour change they found with specific messages about risk, Jones (2009), Rubin (2009), Chor (2009), and Ibuka (2009) all make the assumption that the widespread media coverage and the public health communication about risk from the CDC and WHO played the most significant role in their study population's perception of risk and selection of infection control behaviour such as hand-washing. Duncan (2010) reported that international health bodies were the primary source of information for most individuals during the early stages of the H1N1 outbreak when anxiety about infection is likely to be at its peak, which supports the argument that if populations are responding with behaviour change to risk communication about H1N1 specifically, they are likely getting those risk communication messages from the CDC, WHO, and NIH.

Ibuka et. al., (2010) goes a step further than colleagues and examines the geographical and temporal effects on behaviour change in response to an H1N1 outbreak in a US sample. This study found that respondents willingness to change their behaviour in response to H1N1 tracked media interest in the subject over time. The more interest the media had in the H1N1 pandemic, the more likely hand-washing would occur. However, as media attention waned, as did protective measures. In their review of the literature, Bish & Michie (2010) conclude that effective interventions in the future would account for this temporal effect and that future risk communication should focus on specific demographic groups and on raising levels of the public's perception of the threat of pandemic disease and their confidence in the effectiveness of measures designed to protect against it.

The use of hand-washing as an adaptive behaviour to avoid infection has also been shown to affect travel behaviour during H1N1 outbreaks, in that individuals are unlikely to change plans for international travel during an H1N1 outbreak as hand-washing lowers risk to an acceptable level (Raude, et. al., 2009). This is particularly key to the GLEaM model, as hand-washing behaviour is likely to allow populations to maintain their normal travel behaviour as hand-washing is viewed as a sufficient measure with which to lower risk of infection to acceptable levels for most individuals.

The next subsection will consider the use of non-pharmaceutical interventions for the prevention of onward transmission of influenza, and the selection of hand hygiene as the proxy for behavioural change using NPI in our model, and the challenges presented by this proxy. Section 4 will then begin a discussion of the parameterization of the mild/severe model with this additional behavioural information integrated.

2.15 Non-Pharmaceutical Intervention: Which One and Why?

Not only is it critical to understand behaviour change in a pandemic disease scenario generally, but it is important to find an NPI that will fit a variety of criteria, from efficacy to adoptability and cost-efficiency. There are findings in the literature that support the notion that effective prophylaxis can be obtained via a confluence of behaviour change and NPIs on multiple levels. In one study, a consistent, daily, and multi-tiered NPI regimen was effective for the prevention of lab-confirmed and influenza-like illness: “elementary school students using a 5-layered NPI approach, including hand hygiene and cough etiquette, had 53% fewer laboratory-confirmed influenza A infections and 26% fewer total absences compared with a control group” (Aiello, 2008 reviewed in Vukotich, 2010). In other words, we can have some confidence that NPIs can limit transmission locally. However, it remains relatively unclear which aspects of multi-tiered interventions generate this effect.

Nonetheless, some conclusions can be drawn in relation to specific interventions, notably hand washing, the use of facemasks, and isolation. Specifically, hand washing should, by definition, have no effect on aerosolized virus. Bridges (2003) suggests that the wearing of facemasks can reduce the risk of contracting aerosolized influenza virus, although some authors argue that small aerosolised particles pass easily through standard surgical facemasks (Tellier, 2009). It is also know that aerosol transmission tends to lead to more severe respiratory disease and longer duration of disease.

Furthermore, the above studies focus on transmission among relatively small populations, and the effect NPIs on global dynamics has yet to be determined. This is particularly important in the case of pandemic influenza, where the nonlinearities inherent in epidemiological dynamics mean that even small influences on individual transmission may have notable effects at the global scale, or alternatively that strong influences on individual transmission may only delay global pandemic rather than curbing its extent.

Hand washing and hand hygiene are cited by most major health, safety, and scientific organizations as the single most effective and important prophylactic behaviour against the spread of infectious disease, including influenza-like illnesses (ILL) (Mehta et al., 2014). Several studies have also found that hand washing and hand hygiene are the most readily adopted prophylactic behaviours for H1N1 across a diverse range of populations (Biran et al., 2009; Rubin et al., 2009; Ibuka, Chapman, Meyers, Li, & Galvani, 2010).

Stebbins, Downs, & Vukotich, (2009) states that individuals are more likely to adopt behaviours that are perceived as “more typical” than other behaviours. For instance, the use of alcohol-based hand sanitizer, washing with soap, covering sneezes and coughs, and refraining from touching one’s face showed relatively high compliance as they are “typical”, while the use of facemasks showed conversely low compliance as it is perceived as “atypical” behaviour. This suggests that the abundance of public risk communication that recommends hand hygiene for the prevention of H1N1 focuses on behaviour known to *be readily adopted*, as opposed to behaviour *most likely to be efficacious*.

Summarising the findings from the different sections, public health communication might, therefore, be expected to have a negligible impact on health outcomes in the case of H1N1 given its emphasis on the importance of hand hygiene, which to date has demonstrated negligible efficacy. However, (Snyder, 2010a) notes the more troubling possibility of instilling a false sense of efficacious prophylaxis in the public when hand washing is suggested as an effective behaviour, and similar arguments could be made for other ineffective behaviours (see also Hota & McGeer, 2007). For instance, trust in the efficacy of NPIs as adaptive behaviours to avoid infection has been shown to influence travel behaviour during H1N1 outbreaks, in that individuals are unlikely to change plans for international travel during an H1N1 outbreak if they perceive that NPIs lower risk to an acceptable level (C.-K. Lee, Song, Bendle, Kim, & Han, 2012). In light of this, if hand-hygiene is *not* as efficacious as other prophylactic measures such as social avoidance and travel restriction, then the continued claims regarding the efficacy of hand washing in public health communication are not only inaccurate, but unethical. Demonstrating the possible impact of this miscommunication on public health outcomes using modelling methods could potentially inform future pandemic planning and communication policy.

The fact that more severe forms of the influenza are caused by aerosol transmission suggests that this route of transmission, rather than contact-based transmission, should be the focus when formulating NPIs and policies for infection control. This situation highlights not only the importance of establishing the viability of different transmission mechanisms, but also of understanding the proportion of infections due to the different routes, in order to predict the effect of different NPIs on epidemiological dynamics at the collective scale.

Now that hand-hygiene (HH) has been identified as the most likely and efficacious NPI, it is important to examine the effects of this behaviour in our mild/severe modelling scenario on the key epidemiological indicators I identified in the previous modelling exercise.

2.16 Modelling Behaviour

Here, I introduce a new term ϕ, into the mild/severe model previously in the chapter that captures both the possible efficacy of hand-hygiene in preventing contract transmission that is associated with mild cases of influenza, in conjunction with the likelihood that people are actually adopting this HH behaviour. Essentially, ϕ = the probability of people performing HH x probability that HH prevents mild-to-mild transmission. The new model is below:

$$\frac{dS}{dt} = -\beta_S I_S S - (1-\phi)\beta_M I_M S$$

$$\frac{dE_M}{dt} = (1-\phi)\beta_M I_M S - \sigma E_M$$

$$\frac{dE_S}{dt} = \beta_S I_S S - \sigma E_S$$

$$\frac{dI_M}{dt} = P_M \sigma E_M + (1-P_S)\sigma E_S - \gamma_M I_M$$

$$\frac{dI_S}{dt} = P_S \sigma E_S + (1-P_M)\sigma E_M - \gamma_S I_S$$

$$\frac{dR}{dt} = \gamma_M I_M + \gamma_S I_S$$

Model Structure and Parameterisation of ϕ:

With the exception of the addition of the term ϕ, the model above is structurally identical to the mild/severe model from the initial exercise in this Chapter. In fact, it is useful to consider the mild/severe model previous to this one as a baseline, where the epidemiological dynamics of influenza transmission have continued uninterrupted by any type of intervention. In order to test the possible influence of human HH behaviour on these epidemiological dynamics, those mild/severe parameters remain unchanged in this scenario, and the term ϕ is the only changed variable in the scenario. As the previous outcome indicators from the mild/severe model are still of the most interest to pandemic planners and policymakers, and the findings for this modelling scenario will be organised in the same fashion as in the mild/severe scenario preceding.

As noted above, ϕ represents a combination of two probabilities: 1) the probability that people will perform hand hygiene behaviour and 2) the probability that hand hygiene behaviour prevents mild-to-mild transmission. Thus, the term ϕ in this scenario serves to reduce the rate at which contact is effective in creating disease between an individual infected with mild disease and a susceptible person who has come into contact with them. It is known from the literature review on behaviour change and non-pharmaceutical interventions that precedes this exercise that hand hygiene is a readily adopted behaviour, but that its actual effect on transmission is somewhat less clear.

Therefore, the effects of ϕ are likely to exist on a continuum, and we can assume that 1) the value of ϕ is greater than zero, (meaning there is likely some non-zero effect from handwashing and some probability that people are doing it) and that 2) the value of ϕ is also less than one, where all people are washing their hands as recommended and that this hand washing has a maximally preventative effect on mild transmission. Thus, I set ϕ=.33 in this scenario, to reflect the fact that the performance of, and effectiveness of, hand hygiene are both likely to be moderate.

Findings from the Hand Hygiene Model

As in the previous mild/severe model in this chapter, these outcome measures of interest are important or public health and pandemic planning, and in this scenario aim to provide some insight into whether it can be said that moderate effectiveness from hand hygiene performed by even a limited proportion of people has any effect on the amount of mild disease we may see, or whether there is an effect from hand hygiene on overall epidemiological dynamics. These indicators are as follows: (A) Total number of cases over course of epidemic; (B) Total number of mild cases over course of epidemic; (C) epidemic peak time; and (D) Number of cases (severe, mild, total) at peak. As in the previous mild/severe condition, the findings will be presented and discussed in the context of these outcome indicators.

(A) *What is the total number of cases over course of epidemic*? The total number of cases at the end of the epidemic with the hand hygiene condition included was 988 out of 999 individuals in the model, which, as is also the case in the mild/severe model, results in a 98% rate of seropositivity at the end of the epidemic. The lack of change in overall cases over the course of the epidemic and the maintenance of a fairly high rate means that, even with moderate levels of hand hygiene behaviour that is also moderately effective, the overall case load could still place a significant burden on health systems overall. Moreover, unless there is some way to ensure increased compliance with hand hygiene behaviour or to ensure increase efficacy of handwashing, moderate levels of handwashing are unlikely to have an effect on the overall burden of disease in a mild/severe scenario.

(B) *What are the total number of mild cases over course of epidemic?*
25% of total cases in this modelling scenario with hand-hygiene are mild cases. This is a modest decrease from the previous of percentage of mildly infected individuals in the mild/severe scenario, which was 29%. This is unlikely to be a meaningful decrease from the perspective of large-scale pandemic planning or capacity building activities, but it does point to a downward trend in mild cases, demonstrating the possibility that the current climate of communication surrounding the importance of hand hygiene may be serving some purpose if it encourages people to wash regularly and they comply. Increasing the efficacy of hand-hygiene, either through improved technique or through advances in product technology that allow the public to effectively kill the influenza virus when they wash, could potentially lead to a further decrease in the amount of mild cases seen over the course of an epidemic.

The following findings, (C) *epidemic peak time*; and (D) *number of cases (severe, mild, total) at peak*, are also considered in conjunction here as they are in the mild/severe scenario, and in a fashion that compares mild and severe cases to fully contextualise the potential importance of these findings to pandemic planners and policymakers. Please refer to Figure 2-2 below.

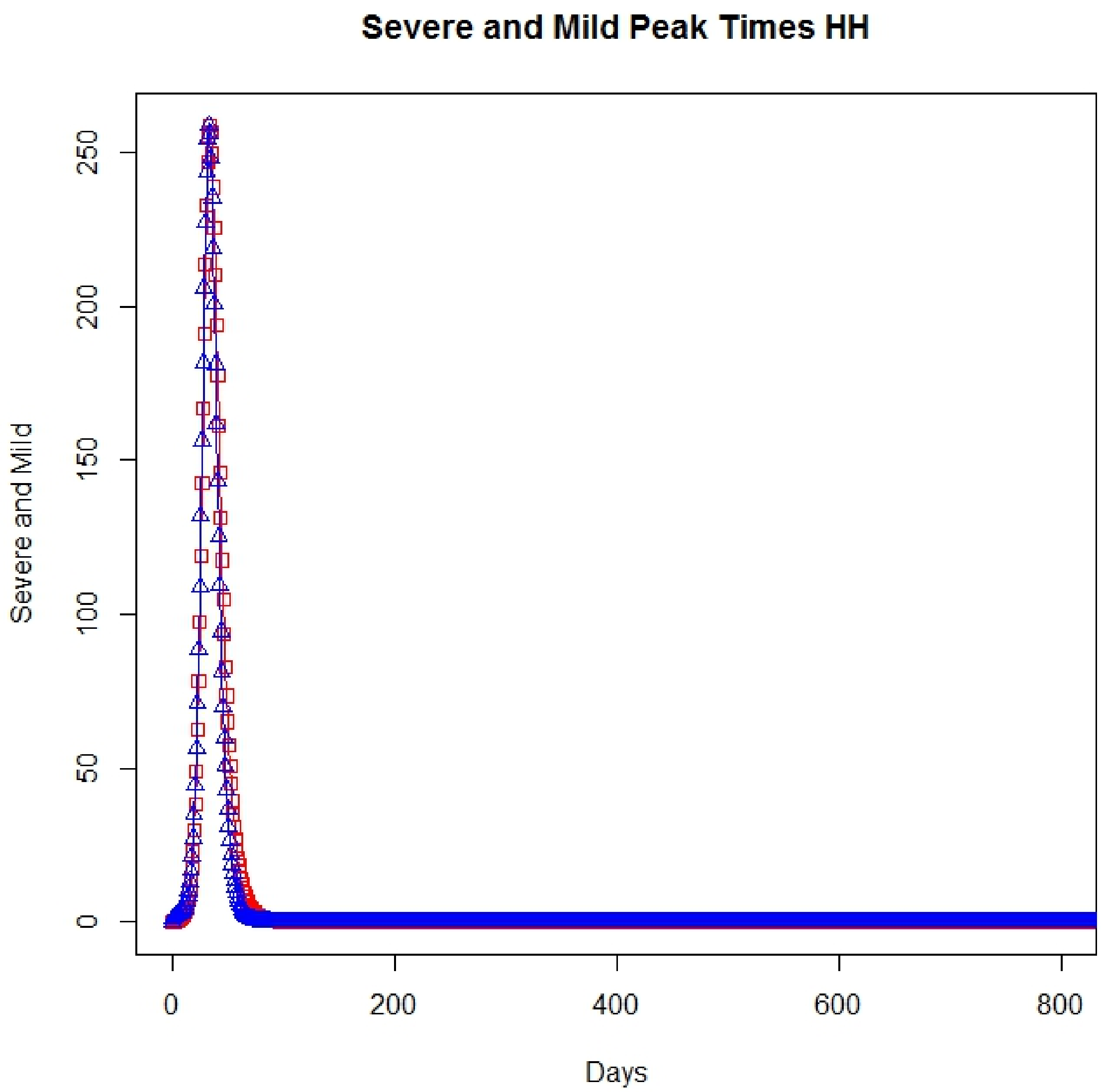

Figure 2-2. Severe and peak times HH.

Sensitivity Analysis and Parameter Adjustments:

In the models above, ϕ represents a combination of two probabilities: 1) the probability that people will perform hand hygiene behaviour and 2) the probability that hand hygiene behaviour prevents mild-to-mild transmission. As previously discussed, the assumptions in the above models are taken from the existing behavioural literature regarding the extent to which that behaviour is likely to be undertaken, and the clinical literature to extent to which that behaviour (hand hygiene) is likely to be efficacious in the reduction of disease transmission. Below, Table 2-3 presents the results of a sensitivity analysis in which the upper and lower ranges of both the efficacy and the frequency of handwashing are explored. The assumptions in these model runs are that the effect of ϕ is likely to both completely dampen the peak of the epidemic at highest probability of both performance and efficacy and that the peaks will reflect the same lack of separation as in the previous experimental conditions.

In these models, the 1) the value of ϕ is either approaching one, (meaning there is a maximal effect from handwashing and maximum probability that people are doing it) and that 2) the value of ϕ is approaching zero, where few people are washing their hands as recommended and that this hand washing has a minimally preventative effect on mild transmission. It is also of note that in the two other scenarios in which *either* efficacy or the frequency of the behaviour is adjusted, there is unlikely to be any observable change from the above model. Thus, this is not explored in the maximal/minimal modelling scenario as, if no one is performing a behaviour, it's efficaciousness is unlikely to matter, and likewise, if the efficaciousness of a behaviour is equal to zero, (no effect), the extent to which someone is performing it unlikely to have any impact.

Findings from the Maximal/Minimal ϕ Hand Hygiene Model:

These indicators are as follows: (A) Total number of cases over course of epidemic; (B) Total number of mild cases over course of epidemic. As in the previous mild/severe condition, the findings are presented and discussed in the context of these outcome indicators.

(A) What is the total number of cases over course of epidemic? The total number of cases at the end of the epidemic with ϕ maximized at .98, (. 99 resulted in no infection whatsoever) suggesting the highest level of efficacy and performance. The infected agents totalled 2 out of 999 individuals in the model, which results in a rate of less than 1% seropositivity at the end of the epidemic. The lack of change in overall cases over the course of the epidemic and the maintenance of a very low rate means that with high levels of hand hygiene behaviour that is also highly effective, the overall epidemic would be practically eliminated, presenting no burden on health systems overall. This would suggest that if there were some way to ensure increased compliance with hand hygiene behaviour and to ensure increased efficacy of handwashing, high, sustained levels of handwashing are likely to have a net positive effect on the overall burden of disease in a mild/severe scenario. Similarly, in the minimal scenario, (ϕ=.02) a corresponding uptick of infected individuals were observed, with all 999 subjects in the model infected. This interesting because in a given scenario of pandemic outbreak, where an epidemic is beginning and no precautionary measures are being undertaken, a high rate of infection could be expected. However, what percentage of those cases might be subclinical due to partial immunity from previous infection or from vaccination is unknown as those variables are not available in the model.

(B) What are the total number of mild cases over course of epidemic?

100% (n=2) of total cases in the maximal efficacy/performance modelling scenario with hand-hygiene are mild cases. This is isn't expected to have any effect on pandemic planning scenarios, however if points to the possibility that when an epidemic is well-contained, there may be a decrease in severely infected individuals, which would in fact have an effect on pandemic planning or prevention initiative. Likewise, in the minimal efficacy/performance scenario, solidly 100% in the model can be assumed to be severe cases, suggesting that with no intervention at all, (or intervention that is ineffective), there is likely to be an exceptionally high burden of disease on health systems.

In general, the sensitivity analysis demonstrates the robustness of the model design, as the model reflects logically projected outcomes given maximal/minimal intervention scenarios. However, the parameterization of the model with appropriate values is still dependent upon the behavioural and clinical literature, and the possible limitations of that parameterization are discussed below.

2.17 Limitations of the Study

As in the figure from the mild/severe disease scenario, mild disease (in blue) and severe disease (in red) peak at the same time. This means that, while hand hygiene at a moderate rate with a moderate efficacy may lower overall cases of mild disease seen throughout the course of the epidemic, it does not seem to have the effect of changing the time at which cases peak, or changing their simultaneous peak with severe cases. Again, the overall value of moderate hand hygiene behaviour is of questionable significance from the perspective of pandemic planners and policymakers, as moderate handwashing behaviour and efficacy seem to have a limited effect of overall disease dynamics during the epidemic, and the small effect it does have in limiting mild transmission is unlikely to have a profound effect on planning or capacity building efforts.

There were some limitations to the methods used in this study. First, parameterising modelling exercises using data from experimental or observational studies always comes with some caveats. A model's ability to predict outcomes is dependent upon the quality of the information available to inform it. As so much of the literature on human behaviour change and influenza transmission is inconclusive, so too are the modelling findings to be considered in the context of fields of knowledge that are still developing. Secondly, both the transmission issues and the behavioural issues considered in the two modelling scenarios are likely to exist on a continuum. This means that the transmission of influenza and the behaviour of individuals are likely to change from epidemic to epidemic in "real world" scenarios, and this model has been developed using general assumptions about epidemics of existing strains of influenza and what is currently known about human behaviour change during them.

Thus, when we consider how both transmission and behaviour might change in the face of an emerging epidemic or pandemic, the generalisability of this model becomes somewhat limited. Finally, time constraints on this exercise prohibited the exploration of the full range of behavioural and transmission scenarios. Adjusting the given parameters as new epidemiological or behavioural information becomes available could dramatically alter the output of the model, and thus, the actions of policymakers and planners considering it. Nonetheless, it has been demonstrated it is possible to integrate human behaviour change into an epidemiological model that considers multiple routes of transmission and different states of clinical severity, providing a richer picture of prophylactic behaviour in a complex epidemic scenario than was previously available.

Further, the parameters in this model were chosen from the best available information in the literature at the time. As discussed in the chapter previously, there is a surprising lack of clarity from the clinical literature as to the details of influenza transmission and symptom severity. These models are merely an estimate as informed by the data that exists, and, like all models, will be prone to error. However, it was a critical task to design a modelling experiment that both accounted for epidemiological and clinical characteristics of influenza as it explored the potential impact of a frequently recommended non-pharmaceutical intervention. As more robust information from the clinical and experimental literature becomes available, these types of models become more robust and predictive by integrating that new data.

2.18 Discussion and Conclusions

In the initial mild/severe modelling scenario, it was possible to use the existing experimental and observational literature on disease transmission and clinical severity to examine the ways in which different kinds of symptoms might have an effect on epidemiological dynamics. his has significant implications for policymakers and planners, as being able to anticipate how many severe cases, meaning cases most likely to need protracted clinical care, is fundamental to the task of building surge capacity, planning staffing, and deciding upon the appropriate risk messaging and interventions to promote to the public. For instance, in the mild/severe scenario, we see that there may be a roughly 3:1 ratio of severe to mild disease. If a planner or policymaker can anticipate an epidemic that is likely to carry a proportionally high number of severe infections, they can adjust everything from staffing to budgetary measures to meet that demand and decrease the increased morbidity and mortality that comes with a higher proportion of severe cases. It is also important for policymakers to know that they are likely to see both mild and severe cases peak at the same time, suggesting that there will be no influx of mild cases that would precipitate the severe ones, and that the epidemic would bring both mild and severe cases to the healthcare system's attention at the same time. This is important information for capacity planning, but also for triage systems, where healthcare workers and transportation workers monitoring fever can be informed that influenza that presents with various clinical features (cough/no cough) have differing impacts on onward transmission, and thus, on overall public health.

When considering the hand hygiene model, the data here suggests that unless the efficacy of handwashing and the rate at which it is performed is increased from moderate levels, this kind of "background" level handwashing is unlikely to have an effect on epidemiological indicators of interest to policymakers or planners. Conversely, this is of some concern to public health communicators who may have a vested interest in communicating about the benefits and limitations of hand hygiene on the public health in a meaningful, factually accurate manner. Understanding that their efforts should be focused on good technique (to increase effectiveness) and frequency (increasing the adoption of behaviour) could help them design more targeted, evidence-informed health communication initiatives pertaining to non-pharmaceutical interventions like hand hygiene.

Suggestions for future work include continued in-depth and systematic review of the literature to ensure that the model parameters as they are presented here are reflecting the most accurate and up-to-date data. It would also be useful to have more experimental and observational studies that explore the actual efficacy of hand-hygiene of preventing or limiting droplet and contact transmission of influenza, more studies that gather accurate data on the widespread adoption and frequency of hand-hygiene amongst the public, and more information about the pathogenesis of influenza with better characterisation of clinical symptom severity.

Chapter 3 - How Does the Use of Contemporary Modelling Tools to Produce Public Health Policy Influence the Public's Projected Health Behaviour?

3.1 Introduction

This chapter will introduce and discuss the public's relationship to the scientific methods that underpin public policies that require behaviour change, focusing on scientific

modelling. The background portion of this chapter will provide justification for a study that was conducted in a general public sample which concludes this chapter. In the background, I will begin by discussing the increase of the use of scientific modelling as a way to inform evidence-based policy, with a discussion of what factors may play a role in whether or not people change their behaviour in accordance with policy recommendations. Secondly, frameworks for the development of modelling knowledge from the philosophical literature are briefly reviewed, including a brief discussion of the influence of formal and informal learning about models on the public understanding and acceptance of these methods. Finally, at the end of this chapter, a study conducted to ascertain the public's confidence in modelling methods, and the public willingness to adopt policy recommendations for behaviour change informed by modelling, is detailed and discussed.

3.2 Background

Scientific modelling is rapidly becoming a primary tool for scientific inquiry and policy responses to some of the most pressing contemporary social and environmental issues such as health and climate change (Feenstra et al., 1998). Public policy recommendations for behaviour change pertaining to issues in science and health are increasingly the result of work with scientific models (United Nations Sustainable Development Programme, 2002). However, although the use of modelling methods to inform policy has increased, the relationship between scientific evidence and policymaking is not always an easy one. Evidence-based policy is usually informed by a range of considerations, including those of interest groups, stakeholders and current political leaders and may also take into account issues such as cost-effectiveness (Mays, Pope, & Popay, 2005). Although these objectives may in some instances act in competition, policy typically has a strong scientific component (Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996).

However, traditional forms of evidence, such as experimentation, don't always provide a clear path from findings to policy recommendations, "research evidence, especially from the social world, is unlikely to be sufficiently clear cut and unambiguous to be translated directly into policy (Elliott, 2000)." While this may also be partially true in the case of scientific modelling and policy, the use of modelling methods to inform policy may have some distinct advantages over more traditional methods of inquiry, such as experimentation.

One of these advantages for policymakers and researchers alike is the flexibility of modelling methodology. This flexibility means that it is possible for a policymaker or researcher using a model to change the parameters of the model in order to explore not only possible outcomes of different conditions, but the impact of different interventions using both existing data and their expert experience, "the output of a model can help the modeller to learn and to develop intuition by playing out different rule sets and initial conditions and exploring their consequences (Boschetti, Grigg, & Enting, 2011)." Models allow for the integration of the assumptions of the researchers or policymakers, in order to project the outcome of a multitude of possible factors that may moderate the response of their intervention.

This facilitates quantifying phenomena in a novel way, as unlike more traditional experimental methods, modelling allows researchers and policymakers to explore possible intervention outcomes in a way that is generally prohibited by other methods. The ability of a policymaker to use a model as an experimental platform in this way, by integrating their personal expertise and insight into the model, is critical because "policymaking and decision-making take into consideration that research evidence may hold equal, or even less importance, than other factors that ultimately influence policy, such as policymakers' values and competing sources of information, including anecdotes and personal experience (Brownson et al., 2009)." The ability to explore the possible impacts of an intervention, or to simulate the impact of behaviour changes in a large population, in a manner that is quantifiable and meaningful to policy objectives, while also being considerate of constraints of time and resources, is almost exclusively the domain of modelling methodology.

The additional circumstances in which modelling is an attractive alternative in the realms of public health science are typically more practical, as both researchers and policymakers are both often concerned with limitations when performing their duties, including time constraints and economic austerity. Modelling methods in particular allow both communities to explore multiple possibilities in limited time frame with fewer material resources than required by other research methodologies.

In this context, the increased popularity of modelling methods to inform public policies that require behaviour change under complex circumstances is understandable. Modelling provides features which more traditional modes of inquiry and policy development cannot, and those features speak to the aims of improving the content of policies under constraints of both the policymaking and research inquiry processes.

Despite the utility of modelling for policymakers and researchers, the success of a modelling-informed policy ultimately depends on public support. Regardless of the sophistication of a given policy or the potential benefits of the behaviour-change recommendations within it, a policy cannot be considered successful if it lacks the support of the public and the recommendations therein remain un-adopted. Unsupported policies are politically costly, and their effective implementation is reliant on the wide adoption of the recommendations they make for optimal effectiveness. Constituency support is not only critical to garnering the political will needed to implement behaviour change policies, but to ensure that the public will actually perform the behaviour changes required (Burgess et al., 2007). The evidence-based policy agenda would therefore benefit from understanding the link between public understanding of the evidence base and their policy support.

In the next section, factors which may influence the public's willingness to change their behaviour in accordance with recommendations made in evidence-based policies are detailed and discussed.

3.3 Behaviour Change, Modelling-informed Policy, and Communication Effects

It is first necessary to understand what underlies human behaviour change in relation to policy recommendations. It is known that a variety of factors influence behaviour change, including, but not limited to: age, gender, socio-economic status, and attainment of education at a range of levels, noting that all of these spheres of individual and social environmental influence may interact in combination to influence what behaviours individuals change and to what extent (McLeroy, Bibeau, Steckler, & Glanz, 1988). Yet, while individual decisions to support policy or change behaviour may be predicated on a range of social and economic variables, increasingly research has focused on individual responses to communication materials (Skinner et al., 1999). Human behavioural responses to communication about risk and health are themselves moderated by several factors.

Two fundamental factors known to influence individual responses to communication efforts are trust and confidence (Siegrist, Earle, & Gutscher, 2003). As Siegrist et al. (2003, p. 706) explain, *trust* relies on social interdependence and that the "objects of trust are person-like entities", while *confidence* is defined as "the belief, based on experience or evidence, that certain future events will occur as expected".

It is important to distinguish these two concepts of trust and confidence, as they are qualitatively different, although may be used interchangeably. Confidence and trust can be delineated by an individual's assessment of risk, "a confidence judgment typically has a very specific referent, and is influenced by base rates and prior probabilities. A trust judgment has a broader scope and referent (Adams, 2005)". Moreover, trust is only an issue in "the presence of risk, uncertainty, vulnerability and the need for interdependency with another person (Mayer et. al., 1995 in Adams 2005)." In the context of evidence-based policy, trust therefore relates to policy-makers, politicians and those who communicate with the public, whereas confidence relates to the evidence base underpinning the policies.

It is also important to consider what the public will do with information that is disseminated in a policy that asks behaviour change of them. In the public realm, individuals seek information only to the point where they feel they have enough information to justify action in some way, and do not examine a policy issue more deeply than is necessary to come to some satisfactory conclusion regarding the action they should, or should not, take (Jenkins, 1999) . The confidence that an individual has in the method that underpins a particular policy recommendation may thusly play a major role in whether or not the individual acts accordingly with the recommendation in the policy.

Further, attitudes toward behaviour change, particularly in the face of uncertainty about a policy issue, may be deeply rooted in the perceived reliability of the communicator, and that perception of reliability is highly context-dependent. This suggests a function of *trust* rather than *confidence.* It is reasonable to assume that even if the trust an individual has in a communicator is somehow compromised, a familiarity with the scientific method used to inform the policy, and confidence in that method, may help moderate that uncertainty and compel the individual toward the adoption of the proposed behaviour change.

It is notable that there is ample discussion in the literature about the effects of trust on the public's relationship to public policy that asks behaviour change, and far fewer examinations of the effects of public confidence in the methods used to inform the policies in question. This creates a gap in the understanding of how confidence moderates behaviour change in the policy-modelling interface, and what other factors confidence may be moderating in this process.

The general familiarity the public has with modelling also plays a role in whether or not they have confidence that the chosen method can accurately inform behaviour-change policy. Despite its utility and increasing use in research and policymaking, scientific modelling as a major methodological tool may not be well understood in all domains. In fact, these methods are often unfamiliar to individuals outside of the fields in which they predominate, and to members of the general public, "(scientific modelling) is an unfamiliar form of inference not just for lay people but even for scientists whose disciplines use observational methods (Pidgeon & Fischhoff, 2011)." This could be identified as a source of reticence to change behaviour in the public, as it is impossible for an individual to make a confidence judgment of a particular policy recommendation if they are unfamiliar with, or confused by, the scientific methods used to come to that conclusion.

Nonetheless, as modelling has become a ubiquitous method for prediction and policy development, there has been an increase in public exposure to modelling methods through media reports about scientific topics and formal education. A search on AlphaGalileo for News Releases including the keywords "model" or "modelling" and categorised under Science, Health, and Applied Science returned 3407 results for the 5-year period commencing 1 January 2003, and 5422 for the respective period starting 1 January 2008.[1]

Evidence supports the idea that media messages on television about science can influence individual beliefs about scientific topics (Hwang & Southwell, 2009), and the Agenda-Setting hypothesis actually suggests that shifting public opinion on a scientific matter may be the result of the extent or salience of media coverage pertaining to that topic (Brulle, Carmichael, & Jenkins, 2012). Finally, the frequency with which an issue appears in media

[1] Search conducted 16 January 2013 using http://www.alphagalileo.org/AdvancedSearch.aspx; defaults used for all other search options.

coverage has been found to usurp actual content in swaying public opinion about the relevance and importance of a particular matter (Andrews & Caren, 2010).

Therefore, the extent to which the public is exposed to the concept of modelling in news reports about public policy issues of importance may be not just be moderating how familiar they are with modelling as a tool in scientific inquiry, but also how confident they are in scientific modelling as a standard part of the scientific process, thereby influencing their willingness to change their behaviour as recommended in policies that have been informed by modelling methods. A “fixed” understanding (or existing mental model) of how “good science” is conducted may stand as a primary barrier to behaviour change when the recommendation for that change is generated from an unfamiliar source (Sterman & Sweeney, 2007) if the public is unfamiliar with modelling as an integral part of that “good science” or policy practice.

In the next section, this critical area of modelling knowledge is discussed, with a focus on the formal and informal learning scenarios during which the public may encounter models. Existing frameworks for building modelling knowledge are also discussed.

3.4 Modelling in Formal and Informal Learning Settings and Frameworks of Modelling Knowledge

In conjunction with increasing familiarity with modelling through its ubiquity in policy, formal and informal education in science may also contribute to public understanding of models and modelling. This is likely to be more prevalent among those having been involved in higher education in a scientific or allied area, as well as among younger members of the population who may have encountered modelling at school. Although there is currently limited focusing on modelling in school science education, authors have commented that increased exposure to modelling and other technologies in the classroom, and encouragement to apply classroom science to everyday situations, would increase the public understanding of modelling technologies (Cajas, 1999) and that “a central role for models and modelling would greatly increase the authenticity and utility of the science curriculum” (Gilbert, 2004, p.127).

Nevertheless, there is some suggestion in the literature that, with even a moderate facility with modelling, or exposure to modelling through formal education, students of modelling may still be considered “novices”, and that there may be a lack of sophistication with, or understanding of, modelling methodology in a general sense (Harrison & Treagust, 1998). The threshold at which modelling knowledge begins to instil confidence in an individual member of the general public has not yet been explored. Contributing to this issue is that modelling is unlikely to be taught as an integral part of contemporary scientific practice in classrooms.

Danusso, Testa, and Vicentini, (2010) argue that the science education literature has demonstrated modelling activities to be used only rarely in science classroom situations, despite demonstrations that even short interventions can support more sophisticated knowledge (Gobert et al., 2011; Schwarz et al. 2009; Pluta, Chinn, & Duncan, 2011). Indeed, a range of studies have shown that both teacher and learner knowledge of the nature of models is generally limited (Danusso, Testa & Vicentini 2010). For instance, without specific instruction, students tended to understand models as miniatures of real-life objects that corresponded in every way except scale (Grosslight, Unger, Jay, & Smith, 1991). Similar studies of public understanding of models are missing from the literatures.

Informal learning scenarios, outside the classroom, may also play a role in the public's general familiarity with models and their confidence in them. Informal learning can be understood in contrast to the formal, structured, classroom-based learning discussed above, however, informal learning is not entirely passive, "informal learning is usually intentional but not highly structured (Marsick & Watkins, 2001)."

In fact, the importance of informal learning for improved scientific literacy should not be understated, "The majority of students' science learning experience actually takes place outside of the formal classroom setting and in informal learning environments, and such learning may take place at home, in museums, through media, club membership activities, or simply in everyday experiences (Gerber, Cavallo, & Marek, 2001)". This is key, as in the previous section, the increased exposure of the public to modelling methods through media reports on public policy issues was discussed, and it is reasonable to assume that this may be playing a role in increasing the general knowledge and understanding of the public in reference to modelling methodology.

However, it should be noted that it is impossible to make specific claims about the role of informal learning in the public understanding of modelling methodology, as there has been little to no inquiry that specifically addresses this issue. Yet, while it is impossible to make direct claims about the role of informal learning on public understanding of the policy-modelling interface, it would likely be beneficial to explore ways in which the public are exposed to this technology and the role this exposure may play in their understanding and acceptance of policies that are informed by it.

While there is a lack of inquiry into the role informal learning has to play in the public understanding and acceptance of modelling methods, there have been many attempts to detail and apply frameworks of modelling knowledge to this issue. Different understandings of scientific modelling are, in part, related to the numerous uses of modelling in science, some of which may be more salient than others for the lay public. Following frameworks on the nature of science, researchers in the science education literature have developed a number of schemes for considering knowledge of modelling.

Schwarz et al. (2009) distinguish between a range of elements of meta-modelling knowledge, grouping these according to nature of models, purpose of models and criteria for evaluating models. Following the evaluation thread, Pluta, Chinn, and Duncan (2011) consider epistemic criteria for good models, comparing the criteria generated between students and experts. Considering notions more in line with the nature or purpose of models, Van Driel & Verloop (1999) distinguish between descriptive, explanatory and predictive models, while Treagust, Chittleborough, & Mamiala (2002) distinguish between 10 kinds of models: scale models; pedagogical analytic models; iconic and symbolic models; mathematical models; theoretical models; maps, diagrams and tables; concept-process models; simulations; mental models; and synthetic models.

However, their framework makes no distinction between models are and what their purpose is.[2] Odenbaugh (2005) focuses on the different purposes of models in science, with a focus on theoretical ecology. Although he acknowledges that the same model may have multiple concurrent roles, his taxonomy distinguishes between the use of models by scientists: to explore possibilities; to provide a tool for simplifying and thus investigating complex systems; to provide conceptual frameworks; to generate predictions; and to develop explanations. This framework has been adopted by Svoboda and Passmore (2011) to the context of science education. Among these frameworks, I choose to focus on the

[2] Although Harrison and Treagust describe their framework as a typology, there seems to be some overlap between certain categories: for example, some of the examples given for *mathematical models* also appear to fit within the description of *iconic and symbolic models*. The framework also suffers from a lack of clarity in the definitions of model types as these are communicated only in the form of examples rather than general principles. As a result, we found it difficult to distinguish between types and discuss this framework no further.

framework by Odenbaugh (2005). This framework appears to provide the most complete and authentic description of the purposes of modelling as employed by scientists, and thus of its uses in the science that underpins policy, as understood by scientists themselves.

In summary, the last few decades have witnessed a shift in the policy agenda towards evidence-based policy development, while in the scientific arena, methodological developments have led to an increase in the use of modelling. Although scientific modelling has become common in the development of policy and in media reports, public responses to these developments remain unclear, be it in relation to their understanding of the scientific methods or confidence in the evidence they provide for use in policy contexts. Indeed, in research on behaviour change policy, attention has focused primarily on the concept of trust and especially trust in expert communicators and governmental entities (Blake, 1999); the concept of confidence has attracted less attention, particularly in relation to a comparison between public confidence in different sources of scientific evidence.

This chapter has detailed a research gap in the literature, specifically focusing on the role of confidence in different sources of scientific evidence as a mediating factor in the adoption of policies that require behaviour change. What follows in the next sections are the methods of a study conducted to fill that gap, and to further explore what confidence the public has in a range of scientific methodologies, specifically modelling, and whether that perception of confidence may moderate their projected behaviours as recommended by public policies.

In this study, I sought to answer two main questions. Firstly, how does the public understand scientific models and their use in relation to other sources of scientific evidence? Secondly, how do perceptions of the source of evidence relate to projected responses to evidence-based policy? To address these questions, I conducted a survey in the form of a paper-based questionnaire that provided evidence in relation to both questions, supplemented by mini-interview data on public understanding of scientific modelling that contributes to answering the first question. In this section, I describe the data collection process, providing information on participants as well as a description of the two forms of data collection and their analysis. After the findings of the study are discussed, recommendations for further research and potential policy implications of the data are detailed in the final section of the chapter.

3.5 Methods

3.5.1 Participants and Participant Characteristics

Participants were volunteers asked at random to respond to the paper-based questionnaire and mini-interview questions during their attendance at one of two public events in a large Scottish city in June 2011. The first of these events was a community science festival and the second a public street festival held the following week that had no explicit science element. Individuals were asked to participate in both the mini-interview and the questionnaire but could decline to participate in either or both. Due to possible difficulties participants might have understanding the questions, participants under the age of 16 were removed from the questionnaire sample, leaving a total of 95 respondents in the questionnaire analysis.

Of these, only 10 participated in the questionnaire only, and an additional 7 the mini-interview only (leaving mini-interview n=102, with 3 eliminated for lack of consent form signature) and 78 total for both the questionnaire and mini-interview together. While the sample size for this questionnaire data is relatively small at under n=100 participants included in the analysis, and cannot provide a significant amount of statistical power, it is of sufficient enough size and depth to provide the basis for an exploratory study such as this which is seeking to characterize the presence, rather than the extent, of a phenomena.

Across the full adult sample, the mean age of participants was 34 years and the ratio of male to female respondents was 47:53. Participants possessed a range of science involvement experiences: 3 reported primary school education, 31 high school education, 26 undergraduate, 15 postgraduate, 7 professional involvement in science; 13 individuals declined to respond. Participants were also asked about the frequency of their attendance at public science events: 12 attended more than twice in the last year, 24 attended one-two times over the last year, 24 attended previously, but not for a while. 15 never attended; 20 individuals refused to respond.

Male subjects responses ($M = 6.10$, $SD = 1.40$) did not differ significantly from female respondents from female respondents ($M = 6.22$, $SD = 1.48$). Neither did the comparison of those who were sampled at the science fair ($M = 3.39$, $SD = .31$) and the public event ($M = 3.47$, $SD = .31$) revealed any significant differences between the groups. Exploration of other demographic characteristics was somewhat prohibited by the high number of refusal responses to these questions and the skewed distribution in some other potential indicators of group difference, such as educational level, but they also yielded no significant group differences. On those indicators however, (especially educational level) there may indeed be group differences, but a larger and more consistent sample is needed to draw more certain conclusions about the possibility of real differences between respondent groups.

3.5.2 Questionnaire

Questionnaires were administered and completed at the site of recruitment. The questionnaire was content-validated by pilot use in a previous pilot study that had provided the motivation for the work described here in the form of the demonstration of a lack of trust in modelling compared with experimental science (Lough, 2011). In addition to demographic questions on age, gender, educational level in science and recent attendance at public science events, the questionnaire contained questions in three main formats.

The first class of questions aimed to understand perceptions of confidence, first by assessing levels of confidence in scientific predictions on the basis of the sources of evidence used, and second by assessing levels of confidence expected by individuals for science that is used as the basis for policy-making. These questions used predefined levels of confidence drawn from the guidance on describing levels of scientific confidence in reports by the Intergovernmental Panel on Climate Change (Le Treut et al., 2007). There were five categories of confidence with explicit numerical meanings: *very low* (less than 1 out of 10), *low* (about 2 out of 10), *medium* (about 5 out of 10), *high* (about 8 out of 10), *very high* (at least 9 out of 10). The second class of questions used standard incremental Likert scales to gauge levels of agreement in five classes from *strongly agree* to *strongly disagree*. In this class of questions, individuals were asked to choose a level of agreement with statements relating to the role of models in science and in policy making. The final class of questions asked participants to select one or more sources of evidence in relation to the following: sources of evidence that they believed to underpin scientific understandings, sources of evidence that would lead them to believe that policy recommendations would be effective, and sources that would lead them to take particular actions.

Categories of sources of evidence, piloted in a previous study (Lough, 2011), were motivated by reading of the science education literature. These consisted of: *Experience of experts*, *Experiments*, *Mathematical models*, *Computer Models*, *Historic studies*, *Current* *data* and *No support* (a fuller description is provided in the questionnaire, available in the online supplementary materials). I wished to distinguish between symbolic mathematical or analytic modelling and simulation. The language used to describe these two modelling approaches was selected on the basis that the terms *computer models* and *mathematical models* were more commonly used on the BBC news website than other terms in the scientific literature used to describe these concepts and I assumed the public would be familiar with them.

I chose the areas of climate change and pandemic influenza as policy-related areas of science where interventions required individual behaviour change. Our interests were in understanding projected mitigation behaviours and beliefs about the behaviour's efficacy, and how behaviours might be related to understandings of the source of evidence supporting them. The influenza mitigation behaviours were drawn from the from the National Health Service Flu leaflet that was sent to all households in the UK in during the most recent H1N1 pandemic in the case of pandemic influenza (National Health Service, 2009) while the climate change mitigation behaviours were chosen among those listed in official UK guidance on climate change mitigation actions on the DEFRA web page 'DEFRA: What can you do?' (Department for Environment & Department for Environment, 2011). Two versions of the questionnaire were developed, one with the pandemic influenza questions preceding those on climate change, and the other with the order reversed. Participants were randomly provided with one of the versions in order to reduce ordering bias.

Questionnaire data were analysed using commercially available statistical processing packages (SPSS 16 for Windows, and R) using descriptive statistics including cross tabulation, Spearman correlation tests, Wilcoxon Signed Rank test, and figures generated in Excel 2007. Any p values of $<.05$ were interpreted to be statistically significant, and where correlations were significant at the $p <.01$ level, this is noted. This combination of statistical techniques was chosen to reflect the need to both quantify our ordinary and normally distributed data, but I made the choice to augment this analysis with the use of non-parametric tests to leverage the flexibility of these tests, and their ability to describe phenomena in data that is non-ordinary or of any distribution. As this paper seeks to characterize a phenomenon rather than to test a particular hypothesis, the use of non-parametric tests was particularly important in conjunction with more traditional parametic approaches to the questionnaire data.

3.5.3 Mini-Interviews

The semi-structured mini-interviews consisted of three questions and were recorded at the recruitment site (see Participants). Respondents were first asked ‘what do you think scientists mean when they talk about models?’ following their response, they were prompted with the follow-up question ‘what do you think (climate/health) scientists mean when they talk about models?’ Finally, individuals were asked ‘what do you think (climate/health) scientists do with models?’ The climate and health conditions were alternated to correspond to the order of the questions in the questionnaire that each individual had been assigned with a view to eliminating possible priming effects. The mini-interviews were administered prior to the questionnaire as the latter introduced ideas relating to possible uses of models, and I wished to avoid priming effects of this type. Responses were captured using a digital voice recorder and converted into MP3 format for transcription and analysis. The MP3 files were then transcribed into text for coding and analysis with NVivo 9.

To analyse the mini-interviews, I employed Template Analysis (Cassell & Symon, 2004), a form of Content Analysis. I began with *a priori* themes from Odenbaugh et al. (2005) relating to the uses of models, as described above. The process of data analysis was carried out as follows. Firstly, one of the authors (RM) read all mini-interviews to familiarize herself with the content. This allowed me to identify excerpts that were poorly described by the *a priori* codes from Odenbaugh’s (2005) taxonomy and to note that these *a priori* codes were better suited for coding responses relating to the *uses* of models than for responses relating to what models *are*. As a result of this examination, two dimensions were constructed - what models *are* and what models are *for* - and additional codes created for the first dimension to create an initial coding scheme that captured the *a priori* and additional conceptions of models arising from the data.

This set of codes was provided to the other two authors (JE and AK) who initially coded a randomly selected sample of interview text corresponding to around 20% of the full set. These two authors (JE and AK) met with a third author (RM) to discuss the initial coding and together developed the final template for coding discussing all problematic cases from the initial coding until consensus was reached. In both dimensions, a category was created to capture responses that were either *non-scientific or vague*; during this phase, no text was coded into categories *generate new ideas* or *theory*. The retained codes were used as nodes in the NVivo database.

It was agreed that text that specifically mentioned a keyword would be coded into the node that corresponded with that keyword. For instance, the participant quote, “models are ways of them trying to understand and analyse the environment, or world, for the purpose of making predictions about weather climate changes, and such”, was coded into the *prediction* node because it used the word prediction. However, some quotes from participants contained none of the keywords, and context was used by the coders to place the quote in the appropriate node. It was also agreed that multiple coding would be applied where participant responses fitted with more than one category; as a result, the number of coded segments exceeds the number of participants.

Finally, two authors (JE and AK) coded the full dataset independently. Once coding was completed I eliminated 34 of the original 99 mini-interviews considered invalid due to the young age of participants (cut-off age of 16 years) or because participants did not respond to all of the mini-interview questions, leaving 65 valid mini-interviews. Reliability coefficients were calculated for the remaining 65 mini-interviews[3] and percentage agreement ranged from 91.58-99.80 %, indicating excellent overall agreement, with an overall Kappa coefficient of 0.96.

3.4 Findings

Findings are presented according to the research questions: I begin by presenting findings relating to the public understanding of scientific methods, focusing specifically on modelling, and then move on to consider their use in policy making. Qualitative findings are presented in conjunction with the quantitative findings where appropriate.

3.4.1 Public Understanding of Scientific Methods

I begin this section by presenting data on the sources of evidence the public believes to underpin findings relating to climate change and pandemic influenza, with specific focus on the perceived role of modelling and consider public perceptions of achievable confidence levels associated with each of source. I then present findings on qualitative understandings of models and their use.

[3] While not all authors approve of the use of reliability coefficients for template analysis, our realist epistemological framework, use of Template Analysis as an extension to Content Analysis, and desire to link conceptions of models to the quantitative data acquired from the survey meant that this was an appropriate approach for our study.

In response to the question asking participants about the sources of evidence believed to underpin findings about climate change and pandemic influenza (Figure 3-3), the most commonly selected sources of evidence for future climate predictions were those of computational models, historic studies and mathematical models (all around 60%), with current data also featuring fairly strongly, but rather fewer respondents indicating a role for experimental methods (around 36%). Both mathematical and computational modelling also featured strongly in responses relating to the sources of evidence for the link between human energy consumption and climate change.

In relation to the analogous question in the context of influenza, respondents selected on average fewer sources of evidence, with the experience of experts and current data figuring most strongly. For these questions, more respondents believed that modelling is involved in predictions about the spread of influenza than in the relationship between behaviour spread. Computational modelling appears to have a stronger public association with climate change research than influenza: 67% of respondents indicated a belief that current evidence for climate change predictions comes from computer modelling compared to 50% in the infectious disease context.

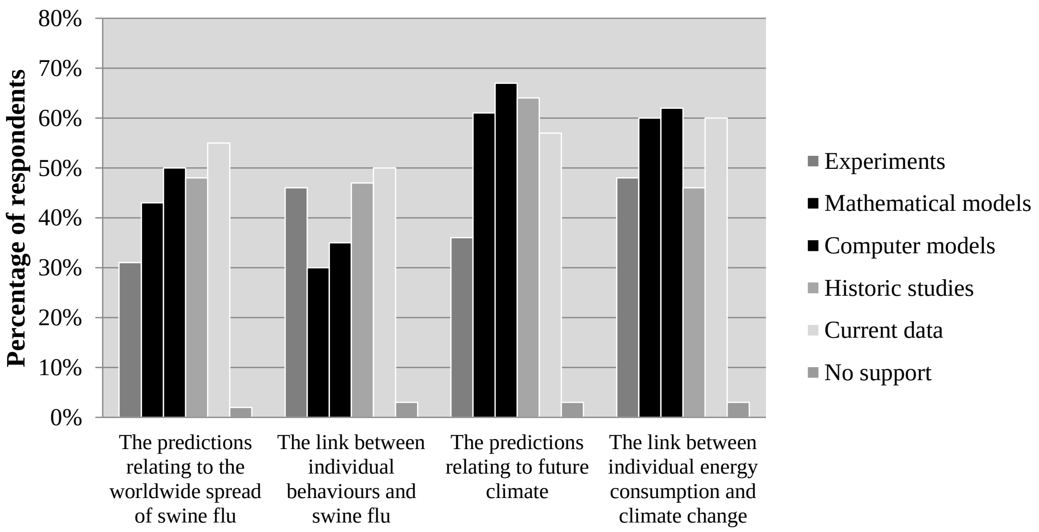

Figure 3-3. Public understanding of data sources for climate change versus influenza. In your opinion, how are the findings relating to the following supported? Perceived sources of evidence for predictions about climate change and pandemic influenza, as well as for the link between behaviour and the two application areas. (Bars are in the same order as shown in the legend.)

The finding that the public acknowledges a role for modelling was echoed in a supplementary question asking whether models were perceived to be a part of 'good science' (see Figure 4-3). In the context of climate change, 78% of respondents agreed or strongly agreed, increasing to 86% in the context of pandemic influenza; responses relating to the two application contexts were positively correlated (Spearman correlation, r=.661, p<.001).

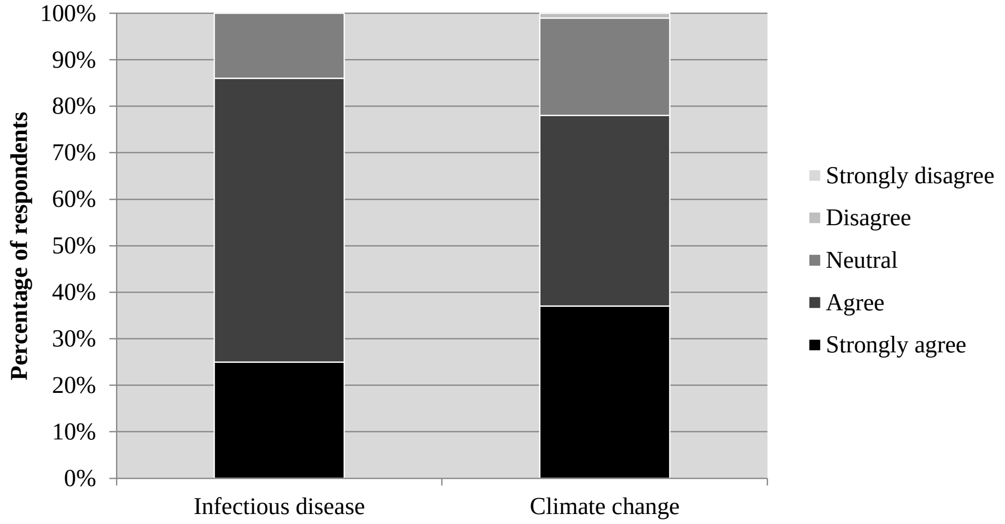

Figure 4-3. Public understanding of the importance of models in science. Percentage agreement with the statement that 'models are an important part of good science' for infectious disease and pandemic influenza conditions.

In response to the question relating to the level of confidence that can be achieved in predictions based on each of the sources of evidence, a relatively clear pattern emerges (Figure 5-3). I focus on responses indicating high or very high confidence (8/10 and 9/10) since medium confidence corresponds to a 50-50 chance of predictions being accurate[4]. Participants expressed the highest levels of confidence in predictions based on experimental science (86% high or very high), with this figure falling to 69% for mathematical models, 66% for life experience of experts and again to 60% for computer models. Historic studies and current data attracted the lowest levels of confidence.

[4] In fact, a 5/10 or 50% probability of predictions being accurate may be considered as successful science and largely sufficient to justify policy interventions, particularly in the context of competing theories or when predicted outcomes have particularly negative consequences.

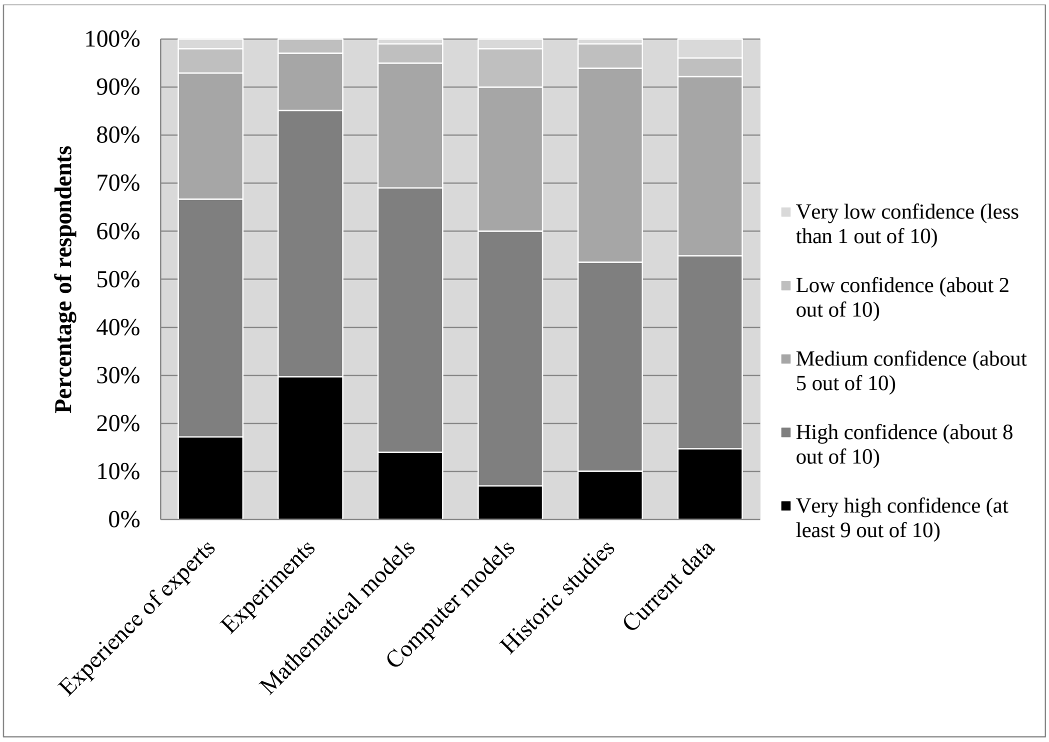

Figure 5-3. Levels of confidence in the various sources of scientific evidence. In your opinion, what level of confidence can we have in scientific predictions or recommendations based on the following, assuming that any research is carried out properly?

To summarise, the diversity of responses regarding the source of scientific evidence in the questionnaire suggests that the public recognises a role for multiple sources of evidence in scientific enquiry, with an acknowledged role for modelling in the context of climate change and pandemic influenza. Although more respondents believed that evidence for climate predictions came from modelling than for infectious disease predictions, fewer respondents believed that models formed an important part of good climate science than infectious disease. Despite the acknowledgement of an important role for modelling in science, participants reported higher levels of confidence in predictions and recommendations based on experimental science than either form of modelling.

I used the qualitative data collected to explore the disparity between apparent knowledge of the role of modelling and lack of confidence in models, by focusing on how the public understands modelling as a scientific approach. As explained in Methodology, we analysed the qualitative interview data along two dimensions: firstly public understandings of what models *are,* and secondly, public understanding of what scientists use modelling *for*.

In the mini-interviews, although most understandings were rather incomplete, it was nonetheless possible to categorise responses according to the extended version of Odenbaugh's (2005) framework. Because I allowed multiple coding, I had data on numbers of coded segments and numbers of respondents providing particular responses; we refer to these as *responses* and *respondents*. Among our coding categories, proportions of total responses ranged from 0.8% to 14.2%. In Dimension 1 the *non-scientific or vague* category accounted for 2.7% of responses, while in Dimension 2, this accounted for 2.1% of responses, collectively accounting for just over 4.8% of total responses. An example of a respondent quote where the answer was classified as non-scientific or vague was the following: "probably talking about … health of people ... I don't know, I really don't know." However, most of the responses that were included in this category included the participant completely deferring knowledge of any sort about modelling by saying "I don't know" or "I'm not sure" or some variation thereof. Of our total sample, only 4.77% respondents were unable to provide a meaningful response in either dimension.

Across all categories, *prediction* attracted the highest number of responses at 14.2% of the total responses (Figure 6-3), with just over 3% more responses categorised in this way than for the next most popular category, *exploration*. Most of the *prediction* quotes explicitly stated an understanding that models are used for predicting future events or trends. For example, the responses categorised as *prediction* typically included this keyword and a contained relatively decisive claim that models are used to predict the future: "models, um, well it's like a system for predicting what's going to happen at some point in the future; put in the information that we know and look forward, or find out, what would happen based on that information." Even where the word "prediction" was not used, models were described as something that may be used to understand what would or will happen through use of the future tense as in the following example: "um, usually it's kind of for health scientists, they are usually working out different demographics or … groups of people or different [drugs] and how it will affect people." Here, the focus is not prediction in the abstract, but the creation by the respondent of a concrete example of a scenario in which scientists might use a model to predict the outcome of a specific intervention.

Overall, the second dimension, the *use* of models by scientists, attracted more responses than the dimension that related to what models *are*. However, a noteworthy proportion of responses to this second dimension were actually provided in response to the question prompt for dimension one. Similarly, the category of *prediction*, which attracted the highest percentage of responses, is in the dimension of what scientists *do* with models.

This suggests that respondents found the uses of models more salient or easier to formulate than descriptions of models as entities, and hints at the idea that public understanding of models as tools used for specific scientific purposes is better developed than their understanding of them as entities.

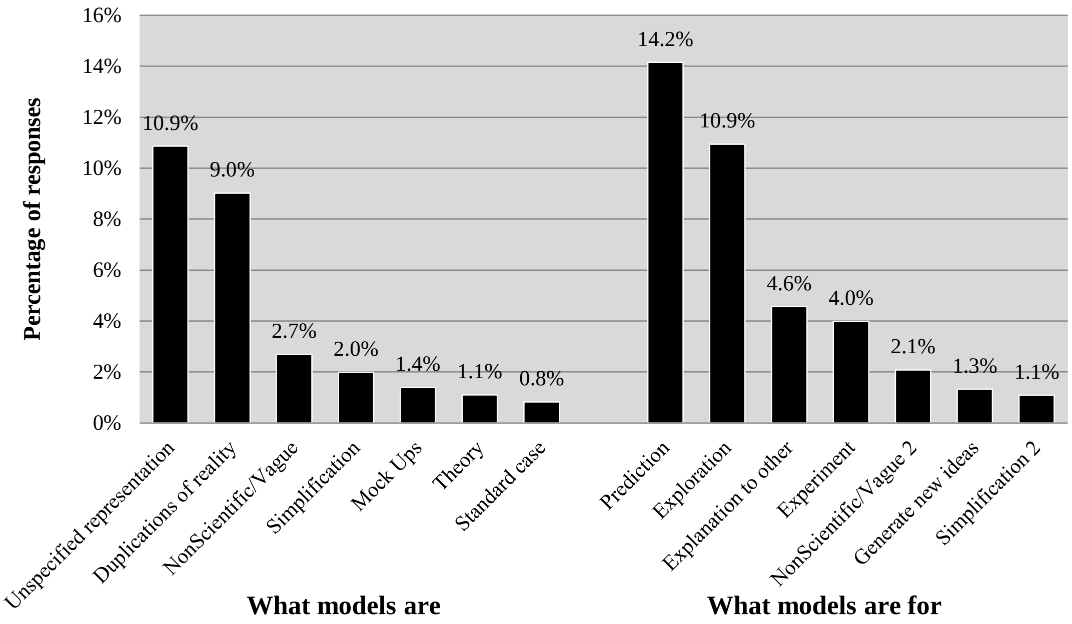

Figure 6-3. What models are and what models are for. Percentages of responses in each coding category along dimension one (left group) and dimension two (right group).

Focusing on the first dimension, the category that attracted the most responses was that of *unspecified representation* at 10.9%, followed by *duplications of reality* at 9.0%. For example, an unspecified representation quote from one of our respondents was: “I suppose like just examples then really, yeah, like a model, yeah, I suppose like an example, almost, of like a kind of general example.” This quote indicated the essence of *unspecified representation* in that the model is understood as a representation of something, as an example to be used, but exactly of what is left vague. Interestingly, models were much less frequently viewed as *simplifications* (2.0%) than as *duplications or copies of reality* (9.0%). Some of the less commonly used categories appeared to be those that relied on vernacular (as opposed to scientific) understandings of the term model: models as *mock-ups* or models as *idealised or perfect cases*[5]. For example, one participant stated, “I think

[5] Although idea of models as perfect or idealised cases may spring from vernacular understandings of the term, it may also refer to scientific ideas such as ‘model organism’ in biology, a concept referred to by 5 participants.

they mean, like, they do a model before they do the real thing first." This quote indicates a fairly precise but concrete understanding of the use of a model as a tool to represent something before it is scaled or built. Finally, individuals tended to provide responses that were coded into a single node. It is possible that this is because their understanding of modelling methodology is very limited, but it should be noted that this may also be the result of the mini-interview format, which was very brief, semi-structured, and did not leave room for prolonged free-form responses.

In summary, the data inform us that although respondents recognise a role for a range of methods including modelling in generating findings about PI and CC and despite recognising modelling as a part of good science in both areas, they have higher confidence in experimental methods. A majority of individuals were able to provide answers to the question of what scientists mean by modelling, and although across the sample there was a good deal of diversity, individuals tended to focus on a limited number of uses, with *prediction* being the most commonly cited use.

3.4.2 Public Views of Sources of Evidence in Policy-Making

I now consider the role of source of evidence in perceptions relating to the application of scientific findings in policy making, focusing on policies that require individual behaviour change in the context of CC and PI. I present data on the level of confidence the public demands of scientists before predictions are used to inform policy that requires specific behaviour changes, which sources of evidence are perceived as being most likely to provide the confidence required, and data specific to the role of modelling methodology in this kind of public policy.

Participants were asked how confident they believed scientists should be in their predictions before the government uses them to create policies that require behaviour change in general, as well as in relation to CC and PI. In the general case, individuals demanded a relatively high level of confidence (84% demanded either high or very high confidence; see Figure 7-3). Interestingly, the level of confidence demanded of scientists was lower for both the CC and PI conditions. Although the reason for this finding is unclear, it may be that respondents required lower levels of confidence in the case where the possibility of explicit adverse effects is relatively clear. Nonetheless, chi square analysis revealed a significant association between confidence required in the general case and CC (χ^2 (9, N=95) = 18.06, p=.034), the general case and PF (χ^2 (9, N=95) = 36.81, p<.001), and between CC and PI (χ^2 (9, N=95) = 37.47, p<.001).

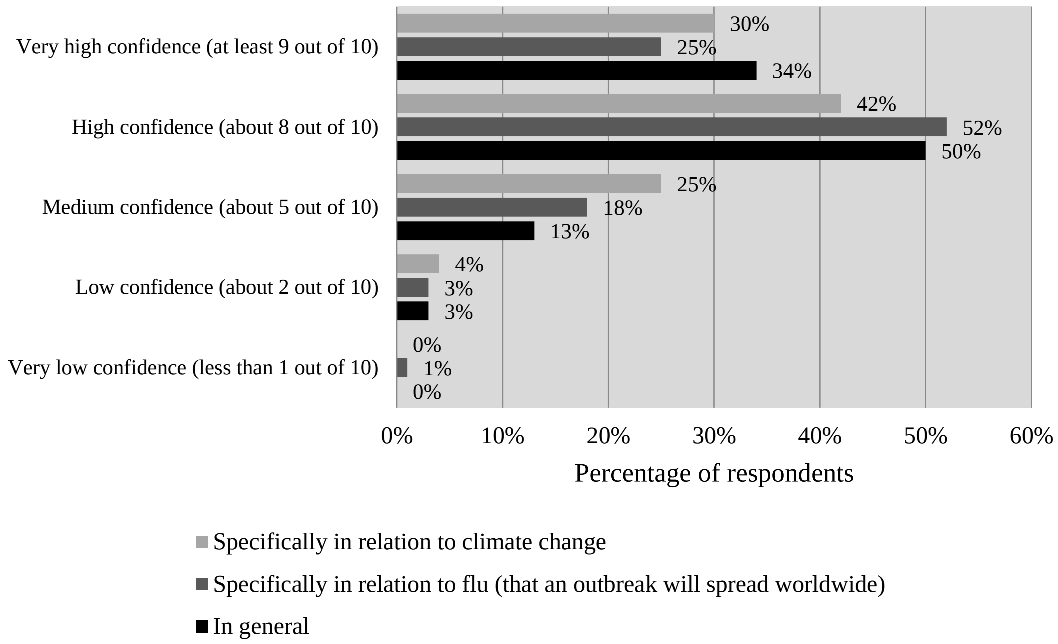

Figure 7-3. Levels of confidence demanded of scientists before predictions are used in policy making.

I was interested in understanding whether participants believed that each of the sources of evidence considered was capable of providing sufficient confidence to be used to inform policy, and whether projected behaviour change was dependent on the source of evidence. To investigate this, I compared perceptions of maximum achievable confidence from each source with overall level of confidence demanded before findings were used to inform policy. For each individual, an index was constructed for each source of evidence that indicated whether the maximum perceived confidence by an individual was at least as high as the level that same individual demanded to inform policy[6]. Findings are shown in Figure 8-3, and show that from the range of available sources of evidence, scientific experiments were perceived as capable of providing sufficient levels of confidence for the highest proportion of participants (68% of respondents). Levels were markedly lower for other

[6] Although it is clear from Figures 5 that experimental evidence is generally perceived as providing the highest levels of confidence, the individual level of analysis provides additional information. Specfically, it is likely that acceptance of policy is contingent on the relationship between perceptions of confidence in the evidence and confidence demanded for the *same* individual.

sources. Interestingly, the life experience of experts inspired sufficient confidence for 51% of respondents, a similar proportion to mathematical models.

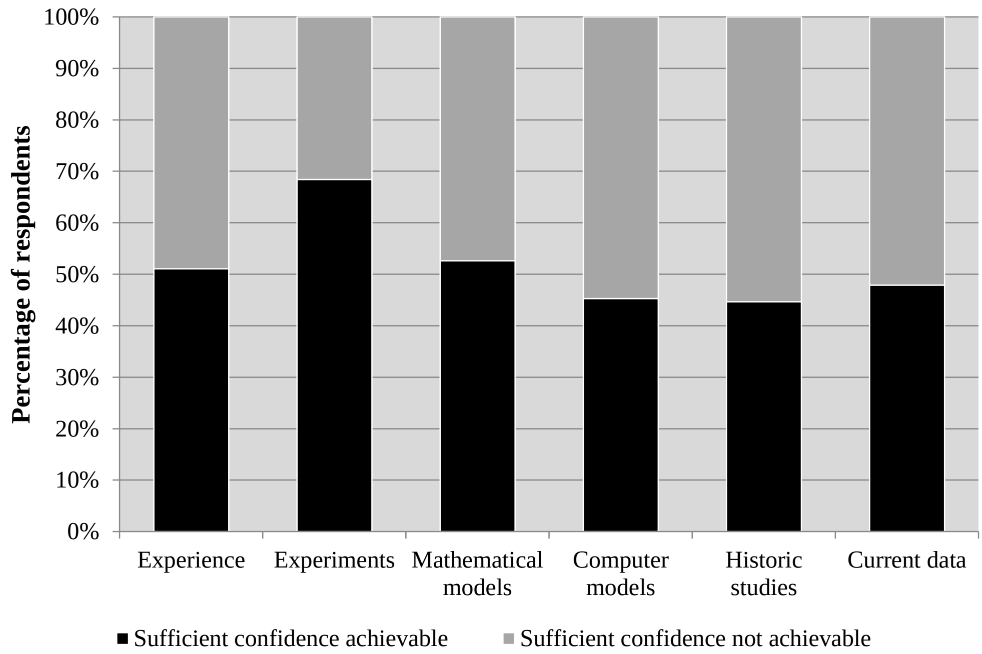

Figure 8-3. Confidence required versus achievable. Proportions of respondents for whom sufficient confidence is achievable for each source of evidence.

A similar pattern emerged from consideration of public perception of methods and projected actions. When respondents were asked 'I would do the following things if the evidence was based on [range of sources of evidence]', scientific experiments were the source of evidence most likely to be associated with intention to carry out each of the six behaviours (see Figure 9-3 for climate change related behaviours)[7]. Interestingly, I see the same pattern as in the confidence responses where the life experience of experts was selected in second position.

[7] A similar pattern can be seen in response to the questions that asked whether respondents believed that policy 'recommendations would be *effective'* on the basis of the different sources of evidence.

	Experience	Experiments	Math models	Computer models	Historic studies	Current data
Buying climate friendly foods	49%	28%	31%	33%	18%	43%
Wasting less food	51%	29%	33%	33%	23%	46%
Flying less and offsetting carbon emissions	43%	34%	52%	50%	22%	54%
Driving less	48%	38%	51%	49%	27%	55%
Choose fuel-saving cars	40%	61%	49%	43%	16%	45%
Buying energy-saving products	41%	57%	47%	42%	16%	45%
Turn down central heating by 1 degree	39%	47%	52%	49%	14%	43%

Figure 9-3. Ways of combatting climate change. The recommendations above have been provided by the Government on ways to combat climate change. How do you think they are supported? Specific projected policy-based behaviour change in relation to sources of evidence to support them.

Specifically in relation to modelling methods in policy, when asked if 'the government should use predictive models in planning for [CC or PI]', although there was tendency towards agreement with the statements (52% *agree* or *strongly agree* in the CC condition and 76% in the PI condition), these values were lower than for the corresponding statements relating to whether models form an important part of good science (Figure 10-3). Notably, a significant proportion of respondents (22%) declined to answer the question on whether the government should use models in planning for CC and although the reasons for this are unclear, this led to markedly lower agreement for the climate change than pandemic influenza condition. Nonetheless, I found a significant positive relationship between levels of agreement with the statement that models are an important part of good science, and responses that affirmed that predictive models should be used in planning and policy for *both* infectious disease and climate change ($r=.583$, $p<.001$ and $r=.659$, $p<.001$ respectively using Spearman correlations), indicating a tendency to hold similar beliefs regarding the role of models in science and in policy making.

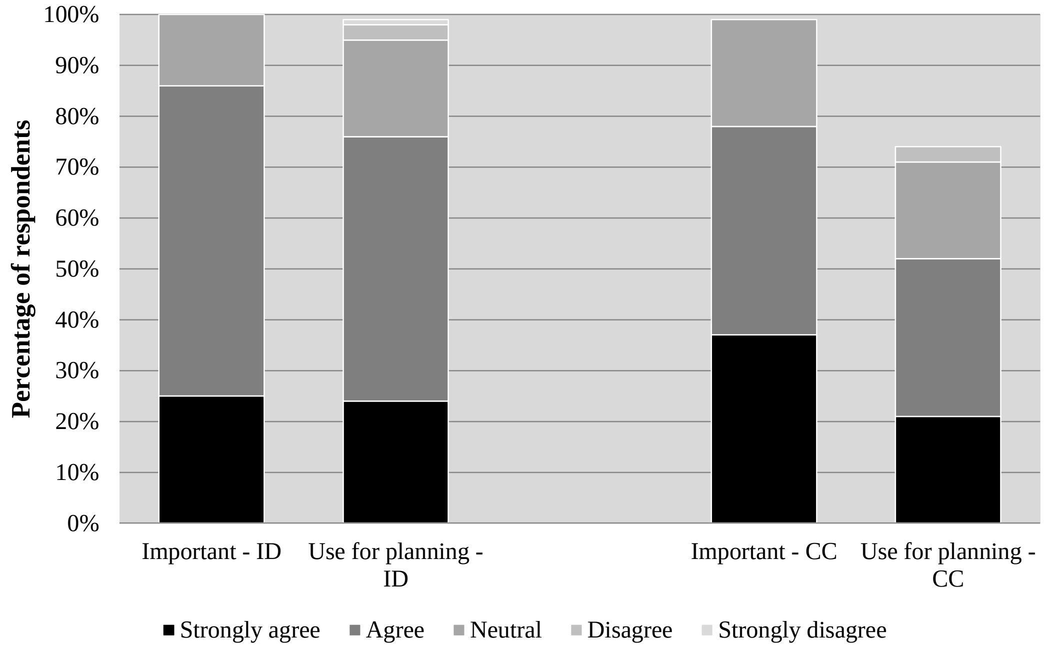

Figure 10-3. Are models a good part of science? Percentage agreement with the statement that models are an important part of good science about climate change (left group) and with the statement that models should be used in planning for infectious disease and climate change scenarios (right group).

In summary, although the public demonstrated a tendency to accept a role for models in government planning, they were more likely to believe that policies would be effective and would be more likely to implement behaviour changes if the evidence for them came from experimental studies. Experimental studies were also perceived as providing sufficiently high levels of confidence to inform policy requiring individual behaviour change for the highest number of respondents.

3.4.3 Limitations of the study

There were some limitations to the methods used to collect our data for this study. First, the qualitative semi-structured mini-interviews did not allow for free-form responses of great length, so it is likely that I missed additional perspectives. Secondly, the issues surrounding behaviour change and the science behind climate change and infectious disease are politically charged and often values-based. I did not ask about individual values or political orientation so failed to capture these moderating factors. Thirdly, there was very little literature on which to base our questionnaire, given the lack of studies of public understanding modelling, and future studies should benefit from the evidence presented here to generate a more coherent picture. As analysis progressed, questions arose as to whether it would have been helpful to collect additional demographic information, including political orientation in the context of policy-related understandings; it may also have been useful to ask specifically about experience in use of models and modelling rather than just experience with science in general. Nonetheless, I have demonstrated that Odenbaugh's (2005) framework can be used as a flexible categorisation scheme for this type of inquiry. I also found it useful to ask about scientists' *use* of models as opposed to just simply inquiring as to their epistemic concept of what constituted a model in the abstract.

Finally, the smaller sample size of the questionnaire respondents, in conjunction with the brief mini-interviews, may somewhat limit the overall generalizability of these findings, and the selection of the participants was limited by my geographical mobility and the limitation of resources to incentivize large numbers of participants, which limits the statistical power of the study. However, the mixed-methods approach of the research strongly suggests that additional resources should be allocated to exploring this phenomenon, and those are discussed both here in the next section and in the extended Chapter 3 conclusions in Chapter 5.

3.5 Discussion and Conclusions

In our public sample, respondents had the highest confidence in evidence from experiments and believe that policies would be effective if based on experimental evidence. Among our respondents, the requirements for high levels of confidence before findings are used inform policy requiring behaviour change are generally unrealistic. This finding suggests the public has an expectation that behavioural recommendations are always made under optimal levels of certainty. Unfortunately, such a functional relationship between science and policy is unlikely to be achieved.

The use of a mixed-method approach was critical to ascertain not only what role models were thought to play in a public conception of "good science" but what the public's conception of modelling itself was. The best way to explore the public's conceptual understanding of modelling was through the semi-structured mini-interview, however, the extent to which these concepts and cognitive constructs surrounding modelling can be accurately surmised through such brief encounters may be limited, but they represent a richer picture of cognition than questionnaire data is able to, hence the design of the study. It was important to both present data on the quality of the public's perception of good scientific practice in conjunction with those conceptions of what modelling methods might encompass.

Our data suggest that confidence in methods, and not trust alone, plays an important role in the projected actions of the public in response to behavioural recommendations in policies. In fact, experimental evidence was found to be more convincing than the experience of experts, the closest source of evidence in our study to a notion invoking trust. Although our study does not address the same kind of questions, this is interesting in light of Brossard and Nisbet (2006) finding that ‘deference to authority’ was the strongest predictor of support of agricultural biotechnology among a ‘low-information’ public. Attending to the confidence the public has in various scientific methods is likely to elicit more direct action from target populations of policies. Confidence may also be related to trust in that, if the public understand how scientific methodology works, and are confident that prevalent methods are scientifically sound, they are more likely to also trust that the advice they are being given to mitigate risk is trustworthy and will be more likely to follow instructions.

Suggestions for future work include more in-depth interviewing and qualitative analysis to gauge the full breadth of understanding of the concepts and functions of models. It would also be useful to understand to what extent projected behaviour change in this study maps to actual behaviour, both in the domains considered here and in others such as social or economic policy. I also suggest investigation with different target populations with varying demographic characteristics.

The evidence presented here describes several different kinds of sophisticated phenomena and relationships, all with implications for the formulation of evidence-informed policies that require behaviour change and how those policies should be discussed in the public theatre. Because of the high expectation of certainty the public has of the scientific findings used to inform policy, and the unlikelihood of that level of certainty being achieved, explicit discussions with the public about levels of confidence pertaining to specific evidence, or about risk, would likely be beneficial toward assuaging unreasonable public expectations.

The public attachment to experimental science is likely due to traditional, rigid conceptions of what constitutes “good science”, an attitude that seems to persist despite acknowledgment that modelling methodology also constitutes an important part of good science in both the climate change and pandemic influenza contexts. Indeed, Dagher and

Boujaoude (2005) report a rejection of historical, non-experimental evidence in relation to acceptance of evolution. This is reflected in the finding that public acknowledgment that a method forms an important part of “good science” does not equate to an acknowledgement that this same method informs “good policy”. Thus acceptance of a source of evidence as contributing to good science is not necessarily enough to precipitate behavioural changes needed for effective mitigation policies.

It may then be beneficial to expose the public and learners in formal education to various forms of scientific inquiry and discuss their appropriateness in given topical situations in conjunction with recommendations. Explicit discussion of the suitability and reliability of various methodologies in the service of specific policy goals may go far to appease public concerns about the methodologies used to formulate behavioural change policy.

3.6 Implications for Policy and Practice

This chapter and the evidence it presents could be used to inform improvements in research practice at it pertains to public policy that is informed by modelling methods. The primary objective of those policies would aim to address the issues of modelling in education and the communication of behaviour-change recommendations in a manner that is sensitive to the multiple socio-demographic and scientific literacy issues that this chapter has identified and addressed. Increased attention to the introduction of modelling methods in formal educational settings, as well as more awareness of the role that public confidence and knowledge in emerging scientific methods has to play in the willingness of the public to enact those policy recommendations.

These objectives could be achieved in a variety of ways, including, but not limited to, a change in science curricula and pedagogical approaches that are improved as far as modelling content, and focused on both formal and informal ways in which learners may interact with models as a concept and as a methodological tool; increased attention to how policy recommendations that request behaviour change are communicated to the public when those recommendations are based off of model-generated evidence, including protocols for strategic communication; and improved communication between the media and the scientific-policy community, to ensure that when modelling methodology is present in widespread media reports, it is accurately represented as a standard methodological tool that is accepted by the research and policy communities as an integral part of good scientific practice.

Options for the development of the aforementioned protocols for communication and education pertaining to the use of modelling for behaviour-change policy will be addressed in a separate, final chapter of this thesis.

Chapter 4 - What is the Nature of the Relationship of Policy Stakeholders to these Modelling Methods and How are They Employed?

4.1 Introduction: The Evidence-Based Policy Agenda and Policymaker Relationship to Scientific Evidence

There is an increasing agenda toward the creation of evidence-based policy that requires the public to change their behaviour to achieve desirable public health outcomes. In order for this endeavour to be optimally successful, the policymaking and scientific communities must collaborate more closely than in the past, and this collaborative effort takes place in an increasingly multi-variate and complex policy environment (K. E. Smith & Joyce, 2012). This collaboration occurs ideally, but not always, in interdisciplinary teams that can include researchers and a diverse array of policy stakeholders (Sutherland et al., 2012). This cross-discipline use of evidence and data from the scientific literature in policymaking opens up possibilities to investigate how policymakers perceive and use the evidence available to them in order to facilitate the evidence-based policy process.

The development of public policy that requires behavioural change from the public is time- and resource- intensive. Sophisticated, effective policy requires behaviour change at many levels, including at the individual, organisational, and community levels (Glanz & Bishop, 2010), and public policies must be designed to account for this. The most successful public health policies are not only informed by a fundamental understanding of human health, but by knowledge of the contexts in which the policies are being implemented, and this includes the social, economic, and political environment (Glanz & Bishop, 2010).

Due to this increase in the evidence-based policy agenda, and the need for policymakers to consider evidence from diverse sources to addresses these multiple levels of influence and context, policymakers may be increasingly exposed to novel or unfamiliar scientific methodologies. For instance, scientific computational and mathematical modelling is rapidly becoming a primary tool for scientific inquiry into a variety of policy-relevant social and public health issues, in conjunction with more traditionally employed methodologies such as scientific experimentation (Coll & Lajium, 2011). As policymakers continue to interact with modelling-based literature and to collaborate with researchers with modelling expertise, is necessary to glean detailed information regarding policymaker perceptions of, and use of, emerging modelling methods.

Having this information is particularly important as the success of the policy-modelling-evidence interface is dependent on involved stakeholders and researchers overcoming a variety of challenges. For instance, the objectives, priorities and demands of policymakers and the scientists they collaborate with may occasionally be in competition. Constraints on time, resources, and differences in epistemology, including research approaches or theoretical frameworks all contribute to roadblocks in the collaborative processes necessary to develop and implement effective policies. This in turn creates a situation in which policymaker access to large amounts of empirical information, and indeed even ready access to scientific experts themselves, may appear to have little effect on policy choices (K. E. Smith & Joyce, 2012). Due to potential social impact of poorly designed or implemented policies, a clearer understanding of how policymakers perceive emerging scientific methodologies in the context of their use for policy development is necessary.

Previous chapters have explored how modelling exercises can be used by non-experts to explore policy-relevant epidemiological issues, and how the public's understanding of modelling methodology might influence their projected behavioural responses to policy recommendations underpinned by these methodologies. In this chapter, I briefly review the literature on scientific evidence and methodology in policymaking itself, and explore policymaker understanding of scientific methodology, with a focus on modelling, in order to identify gaps in our knowledge regarding the question of how policymakers may understand and use scientific information and modelling in the policymaking process.

I then provide a justification for the collection of qualitative data toward the development of a theoretical framework that describes critical issues and challenges using modelling and other scientific methods for policymaking activities. These critical issues and challenges are explored using transcripts of meetings of a major UK policymaker advisory committee that detail their decision-making processes. I then present the body of a qualitative Framework Analysis to address the need for a more sophisticated characterisation toward filling these gaps in knowledge. Finally, I will discuss these research findings and introduce recommendations for the optimal use of evidence in public health policy development and implementation from the supply side.

4.2 Review of the Literature

4.2.1 Brief history

Evidence-based public health policy that requires behaviour change from the public is created in environments informed by a range of considerations, including those of: interest groups, major policy stakeholders, and current political leaders. The development of these policies often aim to achieve maximum beneficial health outcomes with fairly limited financial resources (Mays et al., 2005). The agenda to increase the evidence-base in public health policy often requires that policymakers have direct contact with scientific literature, findings, organisations, and methods (Sackett et al., 1996). Efforts to create and disseminate behaviour-change public health policy with a scientific evidence-base also increasingly demand policymakers to have direct and sustained contact with scientific and health sciences researchers (Sutherland et al., 2012). This process in public health practice and research is also transferrable to a wide array of policymaking scenarios that are not limited to public health. For instance, ancillary population health endeavours in ecology, environmental conservation, and climate change behaviour change policy-making often benefit from the lessons learned in more traditionally-defined public health public health practice (Feenstra et al., 1998).

The model of evidence-based practice in medicine and public health can be used explore possibilities for parallel practice in fields that are critical to population health, like environmental resource conservation (Pullin & Knight, 2003), thus furthering the argument that understanding the processes of public health behaviour change policymaking is central to optimizing the evidence-based population health policy agenda in general. However, because managing the relationship between scientific information and policymaking is not always entirely successful or easy, achieving the best translation of scientific knowledge for use in public health policy development demands that we understand these barriers and their origins.

Some of what is problematic in the evidence-based policy agenda has been identified and discussed in the literature. For instance, the availability, access to, and quality of scientific evidence for use by policymakers has been identified as a critical problem (Black, 2001). For example, Pullin, Knight, Stone, & Charman, (2004) cite poor accessibility and usability of scientific information and a deficit of an appropriate information infrastructure "support" system for policymakers as a key barrier to the creation of policymaking. The authors further suggest that, rather than explore and compare the subjective value of different sources of evidence, it was necessary to glean information from policymakers regarding their perspectives on the availability and ease of access of scientific information in general that they might use in policymaking endeavours. In their findings, they state that the amount of evidence or scientific information actually being used in the service of developing public policy is disproportionately limited compared to the amount of scientific evidence that may actually be useful for informing or driving health policy initiatives.

Pullin, Knight, Stone & Charman (2004) explain the lack of use of available scientific evidence as an issue of operational deficit; this deficit can present as a lack of time. When policymakers are faced with the day-to-day pressures of executing the policymaking process, decision makers do not feel they have sufficient time to access the primary information they might require to judge effectiveness of alternative actions, and thus cannot perform a full analysis of policy possibilities (Pullin & Knight, 2001). Therefore, even when the necessary scientific information is available to policymakers and stakeholders, and even when they are working in collaboration with outside experts, there are still operational and process constraints for policymakers that may inhibit the best use of evidence in policymaking. This evidence supports the hypothesis that when policymakers are lacking the guidance to readily facilitate the appropriate use of scientific evidence and methods in the creation of policy, necessary critical evaluation and use of scientific methods and evidence may be neglected in the policy-making process, and further, that policy decisions may thus be based on anecdote or personal experience of policymakers rather than on data or evidence (Pullin & Knight, 2003).

Conversely, it can be difficult for researchers and research-funding bodies to both understand and identify which research methodologies or findings would be most beneficial to policymakers, a phenomenon which may stem from a two-fold issue: how policy-oriented research is perceived and valued in the culture of the traditional academy, and how research that may be useful to policymakers is identified and supported (Clark & Holmes, 2010). Similar to the operational and day-to-day concerns of policymakers, there are also practical considerations for academics whose research might influence policy or who might be working directly on policy projects. For instance, policymaking bodies or governmental organisations and projects tend to have higher staff turnover rates than academia, making a sustained relationship for an academic group with a group of policymakers difficult, and there may be a perception amongst academic practitioners that most beneficial policy-oriented, goal-directed research exercises are something primarily initiated, or even commissioned, by the policymaking bodies themselves (Clark & Holmes, 2010).

Emerging and increasingly popular scientific methodologies such as computational modelling may present new and difficult challenges for policymakers and stakeholders. These challenges may include policymaker understanding of the technical aspects of modelling, how to interpret modelling-derived findings, or negotiating the limitations of the modelling methodology (Daley et al., 2001). These difficulties highlight why collaborative processes when using modelling methodology to support public policy development in public health is so important: It is critical that policymakers support the inclusion of expert modellers into policymaking teams that wish to use modelling-derived data, who can help policymakers overcome these technical challenges in the policy advice process, ensuring that the quantitative insights they seek are readily available (Van Kerkhove et al., 2010).

The need for policymakers and researchers to build and maintain these relationships becomes particularly evident in urgent public health crises such as pandemics, where policymakers may need to act quickly to employ plans for mitigation and management. Van Kekhove et al. (2010) suggest that scientific information about occurrences such as epidemics may become available too late to be of good use to policymakers who need to make more immediate decisions regarding preparedness or human services during the pandemic or epidemic event. They continue to argue that investigators who are involved in this kind of modelling-derived data should consider involving policymakers in their activities, in order to establish connections and communication channels that can facilitate the delivery of the necessary information in a more timely fashion.

Despite these challenges that both scientific investigators and policy and decision makers face, the use of evidence, particularly modelling-derived evidence, in the process of making policy decisions is likely to continue to trend upward. To assist in addressing these challenges, what follows is a brief critical review of the literature that first explores how policymakers currently use scientific evidence in policy development. The second section of the review discusses the understanding and use of scientific and modelling methodology specifically by policymakers when developing public health programmes and concludes by detailing some possible research questions for further inquiry. Finally, the details of a qualitative investigation into the modelling-derived, evidence-based policymaking process are presented.

4.3 How Do Policymakers Use and Perceive Scientific Evidence in Behaviour-Change Policy Development?

There is still a significant lack of clarity in the research and practice communities surrounding the question of how policymakers use scientific evidence and how to advance the use of evidence and various scientific methods in policymaking. There exists a body of literature on the role of evidence in policymaking, but it can said to be descriptive rather than prescriptive in nature. While some limited theoretical frameworks for explaining the process of using evidence in public policy have been proposed, there is a lack of empirical evidence that supports these frameworks (Granados et al., 2009).

Innvaer, Vist, Trommald, & Oxman (2002) conducted a systematic review of the literature with the aim of summarisng the evidence from 24 studies where qualitative interviews with health policymakers were conducted. Policymakers working on healthcare issues were asked to identify facilitators of, and barriers to, the use of research evidence in their work. Searching multiple databases (including Medline, PsychLit, etc.) in June 2000, Innvar et al. (2002) included interview studies with health policy-makers that covered the policymaker perceptions of the use of research evidence in their health policy decisions at national, regional or organisational levels, and identified by an inductive process of theme development, an array of barriers that may prevent effective collaboration between the research and policy communities. The authors cite the most commonly reported barriers to using scientific evidence being: absence of personal contact with researchers (11 of 24), lack of timely relevance of research (9 of 24), and mutual mistrust or misunderstanding (8 of 24). They concluded that there was often the perception from policymakers of ‘two communities’, where the policy and scientific communities were unable to take the perspectives of the other, and there was a specific finding wherein policymakers felt that information from researchers alone was insufficient for solving critical issues, which required what they termed “political judgment” in addition to evidence.

The identification of what is meant by “use of evidence” was also discussed in the review, and there was a differentiation in the degree to which evidence is used in policymaking. This can be identified in two parts: 1) evidence that is used in an enlightening way or selectively, for instance using a study to inform discussion or deliberation about possible policy alternatives and 2) evidence that is used directly, such as research data being cited in policy proposals to support the strength of the policy suggestion (Innvaer et al., 2002). The use of scientific evidence may also vary in relation to the different types of decision-makers using it and whether or not they occupy upper, middle and lower level positions, with upper level policymakers usually using scientific evidence in an enlightening, informative, rather than concrete, manner. Various types of policy questions: vague and complex, or focused and simple, may demand different kinds of evidence-use depending on the policy goal, and whether the aim is adoption of a health behaviour versus implementation of a programme, or decision-making on issues versus action during crisis. (Innvaer et al., 2002).

Innvaer et al. (2002) concluded that there are ways in which researchers could facilitate the use of their research in policy relevant areas by developing more active, personal dialogue with policy stakeholders and decision makers, designing scientific research that speaks directly to policy objectives, and ensuring that their research is perceived by policymakers as timely, relevant and of high quality. While these suggestions are well-considered, they do place the onus of communication, advocacy, and awareness primarily on the researcher, suggesting that researchers ensure findings are relevant to the current deliberations of policy decision makers and not simple contributions to overall knowledge. Despite this seeming imbalance, there are in fact valid concerns about the adaptation of original research into a policy-friendly format.

Researchers have an ethical imperative to minimize issues such as bias, and policymakers may have interests and political imperatives that compete with those of scientific objectivity, however, assumptions in the evidence-based policy literature appear to support the notion that there is a linear relationship between research-based evidence and policy, which is consistent with a positivist view of science (Black, 2001). Black (2001) argues that accepting this linear relationship places the policy-evidence enterprise at risk by quantifying the value of research solely by its utility for use in policy as judged by the policymakers using it.

This is clearly problematic, as researchers and policy-makers may have competing or counter aims and different accountability needs. As Black (2001) argues, policymakers may have goals other than simply contributing to knowledge or judging the clinical effectiveness of an intervention. They must consider social, financial, operational, and political aims and costs when considering evidence that may not be at the forefront of scientific consideration. Black continues that there are other roadblocks to effectively integrating scientific evidence into policy, in that non-expert policymakers may dismiss research evidence as irrelevant if it is derived from a different discipline, sector, or specialty, or that there may be a lack of consensus about research evidence dependent upon the complexity of scientific evidence, any standing scientific controversy, or multiple interpretations of findings. Importantly, Black also notes that other types of evidence may compete with the empirical in the development of policy, and that policymakers employ a range of information sources when making decisions, including their personal experience, local information about the community, eminent colleagues' opinions, or medicolegal and governmental reports.

In addition to considering the variety of sources of evidence policymakers may use, some of the issues with the effective integration of scientific evidence into policy may pertain to policymaker perceptions of the consensus surrounding the goal of the policy in question. Black (2001) states that the use of research in policymaking depends on the degree of consensus amongst the policymaking team, including researchers, on the policy goal. Evidence can be used rather concretely if it generally supports the team consensus of what needs to be achieved, but can be used selectively if there is a lack of consensus as to what the ultimate aim of the policy should be. Black further argues that scientific researchers might be naïve to the political considerations policymakers are facing. Researchers may have limited understanding of policymaking processes and have unrealistic expectations about what research can achieve in the policymaking environment. Thus, any investigation that would seek to inform or instruct the exchange of information or collaborative process between scientific experts and policymakers would be sensitive to the sometimes competing needs, imperatives, and limitations faced by both groups.

Another key issue in the use of scientific evidence to support policy may come from the divergent ways in which policymakers and scientists view the certainty of findings that result from scientific inquiry, and this includes the way in which scientists may “hedge” their findings, meaning that scientists can be quite sensitive to the limitations of their data and will, when striving to provide proof for something, will add caveats and limitations to their own data—but policymakers may eschew these qualified explanations for a much more simplified, succinct response to a query on issues that scientists find much more complex (Choi et al., 2005). Further complicating the process by which evidence is used in policy, Choi and colleagues (2005) cite the increasing pressure on scientists to comply with the views of governments that are increasingly responsible for setting agendas and priorities for the allocation of research funds, and some scientists might grapple with the concern that research initiatives which pertain to public policy could potentially create incentive for biased scientific practice by panders to trendy policy topics rather than meaningful inquiry.

While Black's (2001) argument places the burden of the process of evidence-integration into policy on the political naivety of researchers, some research has described how policymakers themselves may not use evidence in policies in the appropriate manner, with some policymakers "cherry picking", or adopting evidence into deliberations or policies only if it supports what they have already decided are their policy aims, and are more likely to reject sound evidence when it conflicts with their policy goals. Choi et al. (2005) cite an example, wherein a university research unit funded by the government that was evaluating a government policy programme for effectiveness, but the government was already implementing this programme long before participant recruitment for the randomized controlled trial has begun.

However, there are ways to improve the collaboration of researchers and policymakers toward the aim of effective use of scientific evidence in public policy. Capacity-building for this type of work might include creating institutions and groups that are built around the notion that researchers and policymakers should be working together regularly, providing education for, and ensuring regular employment of, translational scientists, and providing the necessary administrative support to facilitate regular communication and meeting (Samet & Lee, 2001). In fact, research that focuses specifically on the modelling-policy interface conducted as early as the 1990's advocated for increased contact and mediation between modelling researchers and the policy-makers that use their research, citing that the value of the interpersonal relationship between the two groups "cannot be overstated" (Alcamo, Kreileman, & Leemans, 1996, p. 27).

The issue of improving the problem-solving capacity of governmental and policymaking bodies can be framed as an issue of effective knowledge management, where stakeholder partnerships are specifically managed to promote and facilitate a two-way transfer of information, ensuring both that policymakers are effectively using information, and that those policymaking processes are transparent enough to researchers and the public to ensure accountability and improvement if necessary (Riege & Lindsay, 2006). This is accomplished by articulating very clear goals and strategies for knowledge management across the life of a project from its inception, and having plans for implementation and measurement of these strategies and goals that are agreed upon by all involved stakeholders (Riege & Lindsay, 2006).

This knowledge management and exchange model becomes particularly important in consideration of the current climate of open access, "transparent" policymaking and data availability, with transparency in this case meaning there is a public expectation that public officials should be open and responsive about the reasons for their decisions, and restrict information only in instances where there is a clear argument for public safety or larger public interest in withholding information (Curtin & Meijer, 2006). Curtin and Meijer (2006) also point out that far from transparency being a mere "passive right" of the public to know about policymaking processes, its definition extends to include the responsibility that policymakers hold to actively provide the public access to their deliberations, and to do so in a manner that is readily available without major impediments (for instance, via internet or electronic access). This approach to transparency has particularly important implications for policy and outcomes research, as it places the onus of the provision of critical qualitative and quantitative data on policymakers, and allows interested parties to apply analytic methods to examine these processes in the public interest. Such data is employed in the qualitative characterisation of policy proceedings included in this chapter, and this type of policy research is likely to benefit from the continued move toward open access and transparency initiative which allow researchers and analysts free access to this critical data.

Pursuant to this discussion of knowledge management and information access, the identification and use of appropriate scientific evidence for policymaking purposes often falls into the domain of health ministers, non-profit, and governmental directors with little to no research experience, yet there are expectations that their reports and policies will reference and use evidence in order to create accountability for their policy choices, "Public policymakers can encourage more informed policymaking by asking to see systematic reviews on priority issues, commissioning reviews when none exists, and placing more value on such work in their deliberations and in their interactions with stakeholders" (Lavis, Posada, Haines, & Osei, 2004, p. 1555).

There has also been some limited research evaluation literature that aims to help guide policymakers who wish to use scientific evidence in their development and implementation activities in making decisions about which scientific research to use to inform their polices and how to identify quality research and systematic reviews that may be relevant to them

(Lewin, Oxman, Lavis, & Fretheim, 2009). However, there is little analysis that can be found in the literature that supports the impact this actually has on the policymaking process, or how this evidence is used ‘in-vivo’ to formulate models for the specific task of policymaking.

Lavis and colleagues (2004) also identify key issues of transferability of health-systems research into actionable public health policy. When policymakers wish to bring about behavioural change in complex health systems, and wish to use scientific evidence or research to do this, the policymaking body may find that the research, while of high quality, may not account for whether or not a proposed solution will work within the constraints of the healthcare delivery system in which it would be delivered. This issue speaks to an imperative for researchers engaged in health policy relevant activities to consider the implications of health systems delivery when looking at a specific behaviour-change problem, such as HIV prevention.

Even if a potential solution to a particular public health issue is identified by policymakers from a review of the literature or collaboration with researchers, and even when the suggested intervention is potentially feasible and cost-effective, policymakers need to consider another dimension of needs before they can implement a particular policy. Often, since policymakers proposing a particular intervention will need to account for the political, financial, and human resources required to implement a solution to a complex public health problem, they may eschew the research-supported suggestions for alternatives that speak to these other social dimensions of need, despite the pressure on them to justify every decision with scientific evidence (Lavis et al., 2004).

Clear and direct communication with collaborating researchers as to the limitations by which policy is constrained is likely to go some way in fostering an optimal collaborative relationship. If researchers are aware that their work may be abandoned in the policymaking context due to circumstances beyond the policymaker’s control, there may be less conflict between the two communities when there are disagreements about how to proceed. For researchers, understanding the complexities of the healthcare system for which their research may be relevant could be key (Lavis et al., 2004).

As illustrated above, there is some substantial discussion in the literature regarding these issues of how scientific evidence generally is used and perceived in the policy-research exchange, what the challenges of using scientific evidence may be, and how policymakers might view contemporary scientific methods such as modelling. Yet, there is not as much discussion in the literature about modelling-derived evidence in policy, as opposed to the actual use of modelling in the development of policy. This is key to note as this use is only likely to increase as the demand for data-driven decision-making also continues to rise. The next section discusses how the use of modelling methods specifically plays a role in policymaking, and introduces a study that seeks to contribute a fuller characterization of evidence and modelling use in a real-world policy setting.

4.4 The Understanding and Use of Scientific and Modelling Methodology by Policymakers When Developing Public Health Policy

As discussed in the previous section, many forms of evidence, from the empirical to the advice of colleagues, are fundamental to the development of policy and are used by policymakers in various ways with a range of success. For access to primary health research on a variety of topics, policymakers may make use of scientific databases and libraries relatively independently, without much primary contact with researchers, and in fact, they may view this to be the most effective and efficient way for them to inform their polices (Wilson, Moat, & Lavis, 2013). However, with an increase in the use of modelling methods by researchers in research projects that are policy-relevant, researchers are increasingly exposed to evidence generated by these methods with which they may be unfamiliar, and as evidenced in the previous section, the success of the policymaker-researcher interaction may be one of the fundamental building blocks for the success of evidence-based public health policy.

Modelling methodology in particular can be a highly valuable tool for the development of public health policies and can assist in a variety of endeavours that are central to the aims of policymakers working in the area social improvement. In particular, modelling offers the policymaker an opportunity to explore the possible outcome of multiple policy options in complex environments, and can typically provide this at less operational overhead than more traditional methods (Desouza & Yuan, 2013). Modelling methods can also play a central role in exploring policy issues such as the appropriate allocation of limited supplies during an emergency, how many people to vaccinate or how effective travel restrictions are at containing a pandemic (Epstein, 2009). While there are multiple examples of modelling methods that have been used for policy endeavours, there is little literature that explores the perspectives of policymakers on modelling methodology specifically, despite the research community's continued and increasing use of modelling methods in research that policymakers may use to develop recommendations.

There is some limited research to suggest that the role of modelling in public policy development is in question, and that the role of models to support recommendations on the cost-effective use of medical technologies and pharmaceuticals is controversial. What drives this controversy is the degree to which experimental or other empirical evidence should be required to be evaluated or used to inform the model prior to model use (Weinstein et al., 2001). Logan & Graham (1998) note that there is little literature that provides guidance for best use of modelling methods for the kind of multi- and inter-disciplinary approaches most often occurring in the current policy development environment, particularly now when modelling teams from research institutions and universities may be increasingly called to collaborate with policymaking institutions and groups.

Logan and Graham (1998) also describe what they have termed "social factors" in the course of this critical collaboration between policymakers and researchers that can exert powerful influence on the use of modelling methods specifically in the policy development process. These social factors may include the personalities involved, the political climate of the society or of the organizations involved in research exchange, and also the underlying belief systems of the stakeholders and researchers involved. This is particularly important when scientific or outcome certainty is a primary need for policymakers, but speaking in certain terms represents unethical practice for scientific researchers. As discussed in previous sections, the working relationship between policymakers and modellers is fundamental to the success of the policy-evidence interface, and therefore, the social dynamics within and between the two groups warrants careful consideration.

Policymakers are seek a level of certainty that can be used to convince and persuade a constituency or group of stakeholders, as opposed researchers who may be trained to contribute to knowledge in a general sense. In the research community, models may be seen as just another tool used to generate or explore scientific data, whether or not empirical evidence from experimentation is included in those models. Weinstein et al. (2001) argue that some of the controversy surrounding the use of models in policy stems in part from arguments as to whether the role of models is to establish objective truth or to guide clinical and policy decisions. According to Weinstein et al. (2001) resistance to the use of modelling methods in the development of policy can potentially come from a variety of parties who may be involved in the policymaking process, and for various reasons, citing examples of physicians who claim that clinical judgment cannot be quantified, empiricists who warn that input data can be inaccurate, epidemiologists who worry that logical assumptions about cause and effect may be wrong, from technophobes who worry about the model malfunctioning in some way, and from other stakeholders who fear that proponents of a medical practice or product can manipulate models in hidden ways to mislead decision-makers and persuade them into supporting a policy they find unfavourable.

Weinstein et al. (2001) acknowledge that some of these aforementioned concerns may be valid to certain extent, but note that empirical validation of the predictions of these models is often prohibitively expensive or even impossible, but that their conclusions are disseminated widely and form the basis for decisions that involve substantial resource commitments and health consequences. Weinstein et al. (2001) also note that while modelling methods are widely accepted as exploratory tools for planning in other domains, such as defence, and that decision makers in these domains acknowledge the limitations of models but rely on them nevertheless, these models are less accepted in healthcare and clinical medicine but the reason why is unclear. Weinstein et al., (2001) conclude that is inappropriate for policymakers expect—or demand—that models be used solely as tools predict the future accurately, because even when used in a predictive manner, they can only incorporate what is known at the time the model is used to inform deliberations.

Weinstein and colleague’s (2001) conclusion reflects the notion that policymakers are less familiar than researchers with the various uses of models (for instance, exploratory uses) and critically, that they are less aware of the limitations of modelling methods in providing predictive certainty. This is particularly challenging when predictive certainty is typically favoured by policymakers who may be under pressure to forward an agenda in high-pressure, low-resource environments. The expectation policymakers have that certain scientific methods may provide levels of certainty that are unlikely, but desirable for policy, may play directly into the challenges faced in policy-research collaborations. This disconnect between how researchers and policymakers understand, and what they expect of modelling methodology should thus be a focus of further scientific inquiry.

4.5 Research Questions

The lack of literature that directly explores the process of using modelling methods for public health policymaking is, in general, what needs to be addressed. The effective use of these models as possible generators of concrete supporting evidence, or as platforms for outcome exploration in policy settings, also requires an examination of the policymaking process to better inform our understanding of how various policymaker uses of modelling influences policymaking or underpins policy. In combination with the discussions in the literature surrounding the challenges and proposed solutions pertaining to the use of evidence in policy generally, understanding policymaker relationships to modelling methodology specifically can help provide the necessary missing information on what the use of modelling methods looks like in a real world, successful policy setting, what challenges are faced, and how they are overcome. In order to begin to develop a framework for more successful research-policy collaborations in the contemporary paradigm, this study seeks to characterize the following main phenomena:

1) What are the primary challenges that public health policymaking settings experience in using modelling methods to make decisions in real time? And how are these challenges expressed?

2) How are policymakers using the models to inform their policies as deliberations progress in a natural setting?

3) How are modelling exercises used to directly inform policy recommendations?

While these are the primary research questions from the chapter, I am looking to also present a general characterisation of the use of scientific evidence in these types of policy deliberations. Accessing qualitative data that was generated during real-time policy deliberations should provide us with a unique and highly ecologically valid insight into how modelling methods are used and highlight the challenges which present during this socio-political setting

4.6 Method

4.6.1 Purpose

There has been little detailed inquiry as to the process of using scientific modelling methodology amongst policymakers. This study aims to provide a detailed qualitative analysis that will give provide an embedded account of the deliberations, decision making and dialogue that policymakers engage in as they attempt to assimilate, incorporate and evaluate the use of scientific evidence and modelling methods in a natural setting.

4.6.2 Study Design

Data Source and Sample:
In this study, I utilised publically-accessible meeting minutes from the Joint Committee on Vaccination and Immunisations (JCVI), a UK-based statutory advisory committee formed by the UK National Health Service (NHS) in 1981. This committee provides advice and recommendations based on consideration of scientific and other evidence that is used by the UK Government to inform, develop and make policy on issues of immunization (JCVI, 2013). JCVI is not a policymaking body in its own right and has no regulatory function, but functions as the committee which considers evidence for the purpose of informing these policy decisions ultimately enacted by government. JCVI has no statutory basis for providing immunization-related advice to the Scottish or Northern Irish heath ministries however, health departments from these countries are free to use the recommendations and information from the committee in their final decision-making processes (JCVI, 2013).

JCVI develops their advice and policy recommendations based on a group appraisal of what they cite as the “best scientific and other evidence available and reflecting current good practice and/or expert opinion” (JCVI, 2013, p.19) and state that their sources of evidence under consideration include (but are not limited to) the following: advice from international and national bodies (e.g. WHO, ACIP, IoM, NICE); commissioned attitudinal research; commissioned bespoke mathematical and modelling studies of impact and cost; commissioned clinical research to examine safety; commissioned epidemiological analyses of the incidence or prevalence; commissioned operational analyses to assess aspects of implementation; correspondence with key experts; relevant published literature; unpublished data from entities such as pharmaceutical companies; and stakeholders in community organisations. While this list is by no means exhaustive, the sources of evidence that provide the knowledge base for JCVI deliberations are most relevant to our research questions.

The JCVI exists primarily as an advisory entity, and the policy recommendations it generates may be adopted by health departments throughout the UK who are seeking guidance on immunisations to prevent infections and disease. It is important to note that JCVI is tasked with undertaking these policy deliberations explicitly using scientific evidence to inform their debates. They are to consider burden of disease, vaccine safety and efficacy, impact, and cost effectiveness of immunisation strategies. This is a wide range of considerations for any given policy or program, and considering the voluntary nature of JCVI, it may be expected that there would be some limitation, or at least selectivity, when evidence is being considered.

Appointments to the JCVI Chair and regular members are made on merit by the Secretary of State, in consultation with senior officials. Members are not appointed as representatives of their profession, employer, geographic area, or interest group, but rather on their suitability as professionals as measured against established criteria (JCVI, 2013). This ensures a diversity of opinion and expertise, which in turn allows for more balanced debate and skillset when making policy decisions. Committee members serve for an average of three years. Renewal of appointment is not automatic, and suitability for the role is determined by regular evaluation and oversight. This committee is well-regulated, diverse in membership, and presents as a highly-visible and active advisory body with clear policy objectives. As a result their deliberations present the ideal scenario for addressing the research questions outlined above.

Thus, meeting minutes from the Joint Committee on Vaccination and Immunisation (JCVI) pertaining to the use of scientific evidence and modelling methodology for determining appropriate vaccine policy constitutes the primary source of data for this analysis. There are 8 full-committee meeting session minutes included in this analysis, at 15-30 pages each. JCVI meets at 3 main sessions every year, which are held on the first Wednesday of February, June, and October (JCVI 2013). The minutes of each meeting is uploaded online within six weeks of the meeting and are publically accessible, with no special permissions required for access, and in a standard format Word document format. Meetings under consideration for this study took place from August 2012 to October 2014.

The meeting minutes themselves are transcribed from the deliberations and they do not verbatim identify the input of each individual member. Rather, they are a somewhat summarized, generalized recording of the proceedings and deliberations, and therefore some aspects of analysis, (such as identifying roles and stakeholder contributions) would necessarily be limited. The minutes also are unable to provide a detailed account of the efforts involved in consulting with information sources or interrogating experts that occur outside of the formal policy deliberations. Nor do the minutes capture external events that may come to bear on the deliberations in some way, such as media attention or world events.

There are other documents available to the public that are generated from JCVI's work, and they're not included in this analysis. These include consultations open and closed, position papers, actual policy recommendations, white papers, etc. As the primary purpose of this study is to examine the processes, rather than the products per se, of these types of policy deliberations, the focus of this study is on the committee's iterative process of weighing evidence and creating recommendations. It is important to note that the deliberations themselves do not necessarily reflect on the final decisions as they are written in official documents.

Finally, the deliberations used in this analysis deal primarily with vaccinations for Meningococcal B, influenza, and HPV. However, in the course of its duties, JCVI may consider a full complement of infectious agents, and it may do so simultaneously. Different pathogens carry with them a host of varying considerations, and the socio-political and clinical implications of one disease may vary widely from the next.

The Framework Method of Qualitative Analysis:

A Framework Method was used in this study to facilitate a systematic qualitative analysis and summary of transcribed JCVI committee meeting minutes. This qualitative method has been used since the early 1980's, and was originally used for large-scale research in social policy (Gale, Heath, Cameron, Rashid, & Redwood, 2013), but is becoming increasingly prominent as a means by which to approach medical and health policy research. The Framework Method is related to qualitative approaches to analysis like thematic analysis or qualitative content analysis, which seek to: 1) characterise similarities and differences in a data set suitable for qualitative analysis, 2) summarise complex data while maintaining reference to original data, and 3) present conclusions around core themes with the aim of being descriptive and/or explanatory (Gale et al., 2013).

Qualitative Analysis with the Framework Method results in a matrix output: rows (cases, or in this instance, transcribed minutes of JCVI meetings as one set), columns (codes, or themes identified that are relevant to our questions about modelling and evidence use in policy) and ‘cells’ of summarised data. This approach provided a structure where I could reduce, systematically, a large amount of text from the JCVI meeting minutes into summaries in order to analyse it by case and/or by code, if so desired. The Framework Method provided a significant amount of flexibility for this analysis, as a “case” can be adapted to other units of analysis, such as predefined groups, sets, or organisations as the researcher needs (Gale et al., 2013). In this instance, this meant I could reduce our group of meeting minutes into a single set (row), in order to focus on the themes that arose *across* all available cases. I could perform our analysis of the individual minutes and see how themes arose across the whole data set. The summary cells also enabled us to paraphrase specific instances from *within* individual cases (each individual transcript of a JCVI meeting), which gave us the ability to maintain vital links to the original data. The need to reduce, summarise, and to look across our cases as a whole and yet summate from individual cases, made the Framework Method a natural fit for our purpose.

Framework analysis was particularly suitable for this kind of health services research as it could be used to develop multiple themes and sub-themes relating to the use of evidence and models across multiple sessions of policy deliberations. By allowing us to create themes inductively from the text of the meeting minutes themselves, but also deductively from our review of the existing literature, I was able to develop concepts that described or explained various aspects of the policymaking process both from the critical literature review and at a idiographic level, where individual instances of evidence use and model use were evidenced from the transcripts. Themes often included multiple instances across and within cases (as is typical in this type of analysis). However, sub-themes were created when multiple instances from a single theme were ascertained to be poorly differentiated although roughly thematically similar, and when there was a discernible difference in comparison to other instances under the same theme.

4.7 Data Analysis

Familiarisation and Interrater Reliability

Themes were developed both from the research questions and inductively from the narrative of modelling use within the meeting minutes, and deductively from the literature review concerning the use of evidence and modelling in policymaking that precedes this analysis. When thematic categories were considered too broad, or where there were phenomena that could be delineated from one another but still fit into the same thematic group, sub-nodes were created to reflect this difference.

Within the resulting framework matrix, all cases were treated as one set (named “JCVI Minutes”) in order to provide a holistic picture of this activity across time and cases, while individual examples are drawn from specific cases to anchor these observations to the original data. What follows is a step-by-step description of methods that were used to complete the analysis, and concludes with illustrations of each summary cell from the matrix with direct supporting quotes from the original data and the resulting interpretation of the data in the context of our research questions.

Both researchers (JE and KR) thoroughly familiarised themselves with the transcripts by close reading, studying their format, and began to determine which areas of the text supplied information that pertained to the research questions. Each researcher took notes about possible themes that were emerging and which portions of the transcript provided the most pertinent information. Since neither researcher was present during the JCVI meetings, it was critical that our initial impressions of the data were consistent, and that we regularly exchanged notes as we agreed upon themes that were arising from this inductive process.

There were clear instances where JCVI were utilising evidence and modelling to assist in their process and underpin their recommendations. These instances/verbatim examples from the transcripts were highlighted within NVivo and assigned an initial ‘node’ or theme. After building an initial framework of themes, we agreed that we had sufficient notation to begin to generate our framework in NVivo. This process of initial framework building and familiarisation also allowed us to be alert to areas that would be of interest in the process of coding, which was essential considering the volume of data I were examining

After the initial development of the theme framework from review of the dataset, initial coding of a limited number of cases began by two coders in order to establish internal consistency of coding. NVivo version 10 with Framework Analysis capabilities was used to store and analyse data. A Kappa coefficent of 0.97 was generated, and it was agreed that high agreement was established. Regular team meetings were used to facilitate our critical exploration of participant responses, discussion of deviant cases, and agreement on recurring themes.

Coding

Using the framework capability in NVivo 10, nodes were created for each theme and highlighting began on the pertinent sections of text, adding them to nodes, and notes were taken that described how each example may fit into the theme. These were initially larger blocks of text, but as Framework Analysis is supposed to assist in *summarising* complex textual data, it was recommended by the supervising researcher (KR) that attempts were made to highlight the parts of paragraphs that would only be most useful in reflecting the critical area of thematic content

During this process, reflexive notes were created that would assist in the next steps of summarising examples in plain language as well as highlighting examples from the original data that could be used to strongly support those summaries and anchor researcher observations to the original textual data. At that point, any necessary sub-nodes (two in all) were created that served to specify phenomena that, while similar in theme, constituted separate issues and needed to be delineated from each other in order to create a more detailed explanation of the JCVI proceedings during the data interpretation phase.

Summarising and Analysis

When coding of all of the minutes had been completed into the framework, data was summarised into each cell according to the corresponding theme, and matched with specific examples from individual cases that supported that summary. NVivo 10's framework function allows the researcher to easily return to specific examples coded into the themes and place them within cells individually. Some summarisations were lengthier than others, particularly in cases where sub-nodes were added and individual phenomena had to be described within themes. Each summarisation included terminology verbatim from the minutes in order to ensure consistency of operationalisation and to further anchor the summaries of observation to the original textual data.

After the observations across all minutes were summarised in each cell and appropriate illustrative quotes from individual cases were determined for each cell summarisation, conclusions from the summaries and data were extrapolated, which will be presented theme by theme in the "Findings" section following. Format for this findings section is taken from the originators of the Framework Analysis method (Gale et al., 2013). An example of how the cells look after summary has been completed is below in Figure 11-4:

Theme: Modelling In Policy

JCVI Minutes

- **Modelling is considered a complex analysis and takes time to conduct**
- **Data that is provided from various sources, (for instance, from pharmaceutical companies or from other government agencies) must be carefully considered before it is used as a parameter in a model**
- **Deliberations on which data is most appropriate to use in a model or to parameterise a model can be extensive and difficult**
- **Modelling exercises require collaboration with outside entities and must be coordinated, which is also time and resource intensive**
- **Independent, outside evaluation of modelling is often required to limit uncertainty**
- **Current epidemiological data may conflit with the epidemiological data used in a modelling exercise due to changes in transmission dyanmics or control efforts**
- **Models used don't offer societal perspectives on potential policy actions, and this is noted to be "standard procedure"**
- **Sensitivity analysis of models can only be used in certain cases**
- **Issues of cost-effectiveness and economic impact may have to me integrated into a model after the model has been completed as that information frequently changes**
- **Populations the modelling cover may need to change or be adjusted post-hoc in light what population is most affected by a current outbreak of disease**
- **Each stakeholder has a different perspective of approprioate priorities, which can lead to the usefulness of a given model for a particular purpose to be questioned**

Figure 11-4. Illustrating a complete summary cell from the matrix.

Each of the summary points in the cell is directly linked via index in NVivo to a highlighted direct quote (or multiple quotes both within and across meeting minutes) that has been coded across the entire data set. In the cell summary, data is summarised across time for thematic phenomena that has occurred across the data set. In the findings section, these cells are used as the basis of characterisation, meaning they provide data support for the creation of the final themes. Direct quotes from the individual meetings are used to support those characterisations, so “memos” are created on each theme, and finally, are conclusions drawn regarding how the findings have addressed the research questions. Below, these “memos” are presented by theme, and an example of their format, (also following Gale et al., 2013) is below in Figure 12-4. After the findings are presented in this format for each theme, a Discussion section follows which addresses all of these findings in tandem (across themes) as they are relevant to each of the research questions. A discussion of how this data fits into the larger body of work on the use of modelling and scientific evidence in policymaking, and how to potentially improve this process using the characterisation presented here, is given in the final sections of this chapter.

Theme: 'Theme One'

The definition of the theme as agreed upon by the researchers and defined from both inductive and deductive processes is presented.

Nodes: The terms used in coding and any sub-nodes are introduced. This is not the same as a theme, but rather the term that was used during coding and analysis. Whether nodes were abandoned, collapsed into

Summary of data: The information contained in the summary cells is reviewed and explication of those summary points is provided, as well as direct quotes from the original data that support these summaries and explications. Quotes are in italic with direct reference to what meeting minute they originate from.

Characterisation of Theme: Here, the component characteristics that would identify and differentiate a theme that arises from analysis are presented. These are the main points of interest from each summary of data that pertain directly to the research questions.

Figure 12-4. Example of memo format for findings

4.8 Results of Qualitative Data Analysis

Theme 1: "Decision Processes"

This theme captures time constraints, resources, and operational functions of the committee that play a role in how evidence-based policy is made. Project management and administrative concerns that might have bearing on how evidence is used in policymaking is captured here.

Nodes: As decision-making is often influenced by the operational concerns of policymakers, two sub-nodes were defined that encompass two main sub-sets of operational phenomena the policymakers encountered when making decisions. The first sub-node is entitled “informational concerns”, and pertains to discussions within committee deliberations where they had difficulty accessing information that was necessary to inform their deliberations either because that information was unavailable (did not exist) or because there were issues barring the necessary collaborations or data generation exercises that would provide the desired information. For example,

“The Committee noted the lack of evidence on vaccine efficacy, since the vaccine had not yet been evaluated in an efficacy trial” (Meeting Minutes, Feb 2014).

The second sub-node, “operational concerns”, was used to cache all of the concerns the committee expressed about limited resources of time, financial support, staff support, or statutory constraints on the committee’s breadth of operation. For instance,

*“The Chair noted that the JCVI secretariat was not sufficiently resourced to undertake systematic reviews, and suggested specified members consider the issue and report back to the Committee” (*Meeting Minutes, February 2014).

This shows that often there are underlying operational issues that can influence the use of evidence (in this case, the use of systematic review) to inform policy decisions.

Summary of data: Operational factors in general, and operational considerations that fall within the two sub-nodes detailed above, play a fundamental role in the function of JCVI and its use of evidence in its policymaking processes. As in the illustrative example above from the minutes of February 2014, typical approaches to information gathering for policymaking such as critical and systematic literature review may be beyond the reach of the committee due to poor resourcing. This means that even when the committee identifies that it needs data and scientific information, it may be beyond the committee’s capability to acquire the desired information.

Staffing, and ensuring that there are adequate human resources available to continue operations and fulfil the statutory obligations of the committee, is a concern**.** As expressed below,

“The committee were informed that a recruitment drive for a new chair and members would begin shortly. Members expressed surprise that a recruitment had not yet begun and

expressed concerns that the simultaneous departure of the chair and several members could leave the committee with insufficient multidisciplinary expertise to fulfil its terms of reference' (Meeting Minutes February 2013).

Since JCVI membership is voluntary and unpaid, and yet its purview requires that members provide highly technical expertise, finding the appropriate potential member who is well-qualified and is willing to take on the additional work for no pay can be a hindrance to the best use of scientific information or modelling.

Other issues that were coded into the "operational concerns" sub-node include changes in resourcing or shifts in governance that can affect the function of JCVI. While these changes were unlikely to directly affect whether JCVI could access or use evidence optimally, others pertain directly to how JCVI utilises scientific evidence and how they are perceived by other bodies, as demonstrated in the following quote,

"Revisions had been made to describe in greater detail JCVI practice on gathering and assessing evidence. This is to support an application to National Institute of Health and Clinical Excellence (NICE) for JCVI to be recognised by NICE as an accredited source of evidence and advice. This would allow NICE to defer consideration of immunisation-related issues to JCVI, and allow JCVI guidance to be used in the development of quality standards and other NICE guidance" (Meeting Minutes February 2013).

It's important to note here that this is an application that JCVI is making to state its case as an exemplary expert source of information that handles scientific data in the policymaking context in an optimal way, so while this is largely positive, it is important to note that JCVI's relationship with other policymaking bodies and its statutory breadth of function can exert an effect on how JCVI evaluates evidence and how it is understood by the public and other policy stakeholders as a policymaking body.

Other general operational concerns that fall under "Decision Processes" are those procedural issues that are common to most policymaking committees, but in the case of JCVI and similar bodies, may have an impact on how evidence is evaluated. For instance,

"It was further agreed the Committee as a whole should play a more active role in deciding the priorities for the agenda items for future meetings and that in order to be fully informed the Committee should receive the necessary supporting documentation in good

time and that this information should be accessible as soon as it is ready to be shared" (Meeting Minutes, February 2014).

As in the quote above, what on the surface may seem like a quibble regarding time management speaks directly to both the volume of work that the committee is tasked with, and the heavy time resource consumption of doing such work. Committee members would need to have available evidence and information well in advance of deliberations to appropriately comment after thorough review, but epidemiological information can change rapidly in the midst of an outbreak or infection control measure. Here we see the conflict between the committee desiring ample time to consider any new evidence before any deliberations, and that evidence not necessarily being readily available for their review.

Finally, the decision processes by which JCVI evaluates information are themselves debated as a matter of operational concern**,** as we see in the following quote,

"The Committee noted there had been considerable debate in recent meetings regarding the system employed by JCVI to assess cost-effectiveness, and whether this remained appropriate" (Meeting Minutes, February 2014).

This means that not just evidence itself, but systems to evaluate evidence and incorporate it into analysis are questioned and debated by the committee, and questions arise as to whether the appropriate evaluative methods are being used. This can be positive, as open debate about methods and consensus-building about best practices are fundamental practices for such a committee to return high-quality policy recommendations. However, it should be noted that conflict could potentially arise when a panel of experts from a diverse array of disciplines cannot agree on the best approaches and methodologies.

Characterisation of Theme: Decision Processes appear to be able to be divided into two aspects: operational concerns surrounding access to information, and operational concerns pertaining to the day-to-day operations of the committee. While it is more obvious that a lack of evidence or a lack of access to evidence would affect how scientific information is used to underpin policy decisions, it is likely less readily clear to non-experts how day-to-day operations like time management, budget, statutory mandates, and relationships to other committees or bodies also has a significant effect on how committees such as JCVI use evidence in policymaking. This delineation is important because it reveals that the effective use of scientific evidence in policymaking is subject to fluctuations dependant on factors that might not be immediately identified by laypersons as significant.

Theme 2: "Ethical and Social Considerations in Policymaking"

This theme encompasses the relationship of the evidence-based policymaking process to the wider social and scientific community. For instance, how evidence or modelling is used when issues such as accountability to the public and the wider policymaking and scientific communities arise. It also encompasses the ethical obligations to these communities, for instance, the balance of fiscal cost to social good of policy implementation, and the ways in which evidence might be used to weigh those obligations.

Nodes: This node did not warrant additional sub nodes when coding, however, it is important to note that some instances of ethical consideration were much more overt than others. Often, the obligation to the community or the severity of the burden of disease on the community is directly discussed, although sometimes, the social or ethical importance of weighing evidence or making a scientifically- or modelling-based decision in the service of the public good is less overt. While a significant amount of researcher reasoning was involved in making these distinctions, they did not warrant two separate sub-nodes, as they are not qualitatively distinguishable phenomena.

Summary of data: Policy recommendations regarding immunisation programmes and infection control for entire populations have obvious and inherent ethical dimensions. However, how these ethical dimensions are reflected in deliberations that are informed by scientific evidence and modelling methods may not be as readily discernible to outside observers. In general, the following summary of data reflects that, either explicitly or implicitly, the policy stakeholders are carefully considering what the social and ethical implications are when they are considering evidence to inform their recommendations. However, there may be some question as to whether "Ethics" in this context means the committee is conducting itself ethically, in best service of the social good, within the boundaries of its mandate, and whether that would fall into this theme. Those concerns are likely more operational in nature, (e.g. "Is the committee fulfilling its mandated function?") and I found no data that would suggest the committee grappled with ethics in such an operational way. Rather, as stated above, it appears the committee is grappling with the complexities of allocating resources in the general and vulnerable populations.

Concern for the well-being and prevention of disease in specific populations that may be more vulnerable to disease was evidenced at several points in the JCVI deliberations**,** as demonstrated in the following quote,

"The Chair explained that this ad-hoc meeting of JCVI via teleconference had been convened to consider whether a temporary programme should be introduced to offer pregnant women immunisation against pertussis to protect their newborn infants in light of the continuing outbreak of pertussis that is increasing in severity" (Meeting Minutes Aug 2012).

It is important to note that this example comes from an ad hoc, or irregular meeting, of the committee undertaken with the specific aim of protecting a vulnerable population from a current outbreak of disease. This reflects that attention to epidemiological trends and evidence as it changes between meeting periods is just as critical as deliberating current evidence during regular meetings. There is obvious social responsibility reflected in convening on an ad-hoc basis to consider evidence to protect a specific sub-population of people, in this instance, women and their infants.

Resource allocation is an additional consideration the committee is regularly confronted with, and it too has clear ethical and social implications for which the weight of scientific evidence or modelling would play a major role. JCVI is using scientific evidence to determine the availability and distribution of a wide array of prophylactic measures to the general public, or to specific populations that might be more vulnerable to disease, but these decisions often involve the possibility of a trade-off where services in another area may be disrupted, as we see in the below quote,

"There are sufficient stocks of this vaccine to support a temporary programme for at least six months without putting the routine childhood immunisation programme at risk from supply issues. Alternative vaccines would require procurement arrangements that would take some time to put in place" (Meeting Minutes, 2012).

As above, there is a sense of urgency that pervades some types of these deliberations, where the ethical imperative to act quickly and the resources to do so are sometimes in competition, and this is evidenced by the consistent referral to time constraints the committee faces when making these decisions that need to be made quickly. Obviously, this time-element intersects with how easily the committee can procure high-quality evidence or outside expert counsel in the time needed to come to a decision.

JCVI also regularly considers evidence about the safety of a vaccine they may recommend be added to the schedule of immunisation, or be distributed via a temporary programme to attempt to control a current epidemic or outbreak. In these scenarios, the ethical and social considerations are clearer than those of resource allocation, with the committee weighing the possible risk of vaccine-related adverse events against the possibility of protecting a vulnerable population as they do below,

"The benefit of immunisation during pregnancy to infants is likely to outweigh the potential increase in reactions in pregnant women" (Meeting Minutes, Aug 2012).

The burden of risk that JCVI assumes in assessing the risk of adverse events presents a clear ethical issue, and weighing the best available scientific evidence on the incidence of disease versus the incidence of adverse events to make that decision constitutes one of the ways in which evidence is used to help decide ethically fraught or socially consequential issues in policymaking. Sometimes this includes considering evidence that is unclear or contradictory, as the committee notes in the following,

"The committee noted that there is conflicting evidence on the potential for the blunting of the immune responses to the first routine infant immunisation following immunisation during pregnancy" (Meeting Minutes Aug 2012).

And while the ultimate decision is made that the benefits of immunisation in this instance outweigh the risks, JCVI notes that despite their confidence in making the recommendation, they strongly urge further research to address the conflict, thus augmenting their confidence in making statements of risk to the public.

The final data summarisation point is of note, as it addresses not only how evidence might inform or support policy deliberations with ethical dimensions, but how ethical considerations may inform the development of evidence generation exercises, like modelling, These ethical dimensions and the considerations surrounding them are below,

"Quality of life losses in close family members of those affected by invasive meningococcal disease had now been included in some scenarios in the model as requested by the Committee, although they had not been included in the principal analysis" (Meeting

Minutes February 2014).

Here, the need to address the impact of those individuals affected by disease is being integrated into some of the modelling exercises being used to underpin policy recommendations; this is a decision which has clear ethical and social dimensions. Although these social impact concerns are not a standard part of the modelling analyses that were performed by the committee, it is notable that evidence is not only used to support social impact decisions, but rather social impact decisions are being used to inform the development of evidence. This is particularly notable in the context of this study, as it demonstrates a sophisticated conceptualisation of the potential of modelling exercises to explore policy outcomes, regardless of the quality of modelling or its output.

Characterisation of Theme: While it is clear that the entire enterprise of JCVI has social and ethical dimensions and impact, it appears that those considerations are more explicit and overt in some scenarios than others. Ethical and Social Considerations as a theme should thus be characterised by both the explicit and implicit discussions of actions that have a social or ethical impact, but also the integration of social and ethical concerns into modelling exercises or commissioned studies that seek to provide information to the committee.

Theme 3: "JCVI Attributes"

This theme is concerned with the characteristics of the committee: its scope, role, and membership that might have an influence on how evidence is accessed, used, and interpreted in the service of policymaking.

Nodes: There was significant coding overlap with this node and operational concerns outlined in memo one. For instance, the need for members to be at an advanced level of technical proficiency and educational qualifications, and the need for these members to have no declarable conflicts of interest (for instance, no personal financial involvement with vaccine manufacturers), are attributes of the committee and its functions. But because these functions as they were coded overlapped entirely with the data presented in Memo 1, and the characteristics of JCVI that would influence evidence use were determined to be subsumed under "Decision Processes", this node was collapsed into that theme.

Theme 4: "Modelling in Policymaking"

This theme describes the use of modelling methods specifically to underpin policy decisions, including assumptions and functions of modelling methods in the process of policymaking deliberations, and the operational concerns (time, money, etc.) surrounding the use of modelling to inform policy.

Nodes: This node did not warrant additional sub-nodes when coding as the definition of the theme was broadly encompassing, and the discussion of modelling methods in the original meeting minutes text was well-characterised and straightforward. As I was not focusing on the types of modelling being used or their specific evaluative purpose beyond their use as a source of evidence to underpin policy recommendations or to inform policy deliberations, no sub-nodes were created for different types of modelling or specific uses of modelling. Rather, the summary of data aimed to generally characterise how the models are used and perceived, and what challenges and issues arose when employing them.

Summary of data: Modelling in JCVI deliberations appears to be a fundamental and regular tool used to evaluate scenarios, generate data, and explore possible impacts, costs, and outcomes. However, the role modelling plays in policymaking deliberations seems far from a simple one, with modelling exercises often characterised as someone burdensome, as we see in the following,

"These complex analyses would take time to conduct" (Meeting Minutes, August 2012).

The picture of modelling as a complex endeavour that can place serious demand on JCVI time resources is confirmed across meetings and topics, appearing again here, with the

"The extensive deliberations since 2011"

on the appropriate parameterisation of a model is mentioned in the June 2012 minutes, with an additional note directly after stating that,

"cost-effectiveness model had been revised twice since first being examined by the Committee."

There is a sense from the above quotes that the need to continually deliberate what information should be included in the model, and to adjust the parameters as a result of these deliberations, is frustrating.

There is also the issue that arises that, even when the parameterisation or adjustment period of the modelling that takes place, the model needs to be validated using an outside source in the form of review, as noted by the committee below,

"an independent review of the input parameters and modelling, a report on which had been provided to Committee" (Meeting Minutes June 2012).

This review would obviously require external collaboration and fiscal resources that a non-budgeted committee like JCVI would find difficult to grapple with. However, it demonstrates that JCVI is consistently thorough even when faced with challenges, and appears to be indicative of how evidence is used and validated in JCVI deliberations. This contributes to the impression of JCVI as an entity that is using the highest-quality available evidence to support its decisions.

Although this inquiry is not focused on the various types of modelling here per se, JCVI may also need to consider multiple types models when considering a single issue, such as a cohort model and then a transmission model. This is also true for the various sources used to inform the model. Committee members are tasked with the consideration of data from a wide range of sources, including: governmental data, data from pharmaceutical companies, evidence from other committees, etc. Gathering and evaluating the quality of this evidence is likely to be time intensive and open to much debate amongst members, as seen here in the extract below,

"The Committee agreed that all stakeholder comments received and all recently published evidence had been properly considered by the Committee at its meeting of 2 October 2013 and those changes requested in light of those deliberations had been appropriately incorporated into the impact and cost- effectiveness model presented to the Committee" (Meeting Minutes, February 2014).

Across cases, uncertainty surrounding whether the parameters used in the model is a common theme, as evidenced by the following,

"The Committee noted that uncertainty remained regarding a number of key parameters"

and the primary concern was that, in some cases, that range of uncertainty would cross a certain threshold of a determining factor like cost-effectiveness, which could "make-or-break" a particular immunisation programme. This concern is expressed in this excerpt,

"The three iterations of the cost-effectiveness model presented to the Committee had ranged between positive and negative cost-effective prices, and it was possible the range of uncertainty present in the final version of the model crossed the threshold between cost-effective and cost-ineffective" (Meeting Minutes, February 2014).

This is an interesting point of note, as uncertainty seems to be driving the modelling exercises at this point, and the hope seems to be that the committee can add and remove parameters or ranges of uncertainty until a favourable outcome is reached. There's no discussion on how a model is chosen as the "correct" one once multiple iterations of the model are made and parameters changed. It does seem to be that the model is so fundamental to underpinning decisions as a form of "evidence" that the policymakers will re-parameterise the model until it shows a favourable outcome. Clearly, this is not the best or most meaningful use of this kind of scientific evidence.

However, the JCVI does seem to have some procedures available to them that can assist in limiting uncertainty when using modelling exercises and perhaps mitigating the aforementioned data "fishing" that appears to be taking place in the example above, as in the following,

"This, as set out in the Code of Practice, would ensure relative certainty that the vaccine would have a net positive impact on the health of the population" (Meeting Minutes, February 2013).

The JCVI code of practice in this instance seems to function as a touchstone where assuring the net positive of outcome for the public health is an appropriate answer to uncertainty, particularly when the uncertainty involves questions of cost effectiveness versus the overall health benefit to the population.

Characterisation of Theme: Modelling is clearly a fundamental, necessary tool in the policymaking process. Modelling is flexible enough to integrate evidence from a wide variety of sources, including societal and ethical impacts, however, there do appear to be instances of using the model over multiple iterations in order to gain a favourable "evidence outcome" to support a desired programme or initiative. Modelling is both central to the committee's deliberations and presents a wide array of challenges, both in time and cognitive and deliberative effort.

Theme 5: "The Nature of Evidence in Policymaking"

This theme is concerned with the evidence the committee uses to underpin its policy decisions. This includes access to scientific information, commissioning of scientific studies, the use of published literature or systematic review, and the different types and sources of data the committee uses.

Nodes: This node did not warrant additional sub-nodes as it is inclusive of various types of evidence, identifying any barriers to attaining that evidence, and using that evidence to inform policy deliberations. While it was not useful to parse the specifics of each type or source of evidence in order to form a more general characterisation of evidence use in this context, it was necessary to understand the variety of sources used to provide evidence and the challenges that JCVI and similar committees may have in accessing them.

Summary of data: Even within a single case (meeting) the JCVI may consider evidence from a wide range of sources on a wide range of topics, taken from the August 2012 minutes alone, JCVI considered evidence from the following sources as we see below,

"an analysis had been produced by the Health Protection Agency (HPA); Latest epidemiological data from England & Wales; Summary of Product Characteristics (SPC) (from a pharmaceutical company); evidence gathered by the HPA and MHRA on analyses of the impact and cost effectiveness of strategies; peer-reviewed studies in the literature." (Meeting Minutes, August 2012).

This quote above suggests that one major issue pertaining to evidence use in this context is the high level of variability of data source. The committee is responsible for choosing which source is appropriate for which kind of data or evidence as well as being responsible for determining what the quality or usefulness of that data is. Having to rely on such a variety of sources and types of data may additionally burden this selection process and effect deliberation. Frequently the source of the evidence being used to inform the committee is not readily discernible from the meeting minutes. However, as noted in Theme 1 "Decision Processes" above, operational concerns, such as lack of resources may keep the committee from employing more traditional evidence bases, such as systematic review.

There are several points in the JCVI deliberations where the committee perspective on the quality of the evidence they are using is mentioned, as it is here in the following,

"A number of substantial and well-considered consultation responses"

and in the following quote, even denoting where there was,

"lack of evidence on vaccine efficacy"

or lack of evidence on

"*other topics of deliberation*" (Meeting Minutes, August 2012).

But the sources of evidence and scientific consideration that JCVI encounters extends beyond the traditional as the committee also considers the deliberations of other organisations and entities in its decision-making, as noted in the below extract,

"Committee noted the plans of other administrations in the UK" (Meeting Minutes, February 2014).

The impact of these peripheral or "grey" areas of evidence-gathering should not be underestimated, as the findings of other committees or administrations may have direct impact on what JCVI chooses to recommend, as seen in the above excerpt.

The committee also participates in a fair amount of "horizon scanning", meaning they are looking forward to studies or initiatives that will generate data that can assist them and discussing their usefulness for purpose. For instance, they discuss an upcoming study in the following quote,

"The committee considered that such a study would be very helpful given the planned extensive use of this vaccine in children and supported this study" (Meeting Minutes, February 2013).

They will typically note that they support or endorse the activity, and while there's no formal impact of the committee doing so, such endorsements bring into relief a direct relationship between primary research and policy, and how policymakers desire research that assists them in their understanding and their activities surrounding recommendation development.

Occasionally, JCVI will even go so far as to state explicitly that a particular study for which there is no plan would be useful,

"it would be very important to study the impact of the temporary programme" (Meeting Minutes, February 2013).

This kind of direct and open communication can be rather beneficial to researchers who are interested in applied outcomes in setting a research agenda, although it is not necessarily desirable for a government committee to dictate which outcomes research would be most "useful" if that could be construed as coercive to researchers. Yet, it is important for the committee to be transparent and communicative about where it is lacking information and evidence base.

Characterisation of Theme: While there is a wide variety of evidence that the committee has at its disposal, time and resource limitations may prohibit them from using all desirable forms of evidence. Sometimes the evidence is simply not extant. However, there is a time and resource demand even when the evidence is available as the evidence must be reviewed and judged for worth and fit-for-purpose. Finally, the committee is very communicative when it lacks evidence, when evidence is contradictory, or when it decides a particular study is warranted.

4.9 Discussion

What follows is a discussion of this data in the context of each research question and in the context of the literature. Here, how the data above addresses research questions is summarised. Suggestions for future research, how to use these observations to improve the use of evidence generally, and modelling more specifically, in policymaking endeavours, and limitations of this study, are given in the final Conclusions section.

1) What are the primary challenges that public health policymaking settings experience in using modelling methods to make decisions in real time?

As is clear in the emergence of the sub-nodes in Theme 1 "Decision Processes", the primary challenges to the use of modelling methods (and evidence in a more general sense) appear to be operational. The committee often expresses it does not have sufficient time, money, information, or access to use modelling successfully, and this is particularly true for deciding what data to use for the parameterisation of models and how to determine which evidence they have available is the most "certain", to ensure that the model outputs are actionable. Rychetnik (2002) notes that the appropriate use of evidence in healthcare settings requires a tripartite approach as follows, 1) It must be determined if the research is of high enough quality to underpin a decision on whether or not to implement interventions or policy, 2) the research outcomes must be determined, and 3), whether the available research is generalisable to the potential target population must be determined.
Such a multi-phase process of evidence evaluation, while a thorough approach, is likely to compete with the time pressures evident in the committee deliberations. Time pressure is thus likely a primary challenge for committees operating in public health contexts where the need to evaluate and integrate evidence is central to decision-making.

The committee's model of operation demands that it justify all decisions with an evidence-base. In absence of scientific certainty, using models as that primary evidence base may fall short of expectations of predicting an optimal outcome. Communicating that scientific uncertainty in the name of transparency as a public entity requires a careful command of policy craft. The ability to negotiate scientific uncertainty, develop persuasive communication surrounding policy recommendations to ensure public buy in, while also implementing a standard transparency policy may be severely limited by a lack of dedicated resources and established best practices (Brown et al., 2015). As the committee expresses concern about resource allocation and certainty about the strength of evidence, and is under pressure to ensure all decisions are completely evidence-justified, this uncertainty-transparency interface is also another primary challenge both identifiable in the literature and evident in the findings of this chapter.

However, despite the concerns that the committee expresses about the quality and availability of data to use in the model, they seem to be able to use the data generated by their modelling endeavours to underpin immunization programmes in such a manner that their proposed programmed go on to be successful and improve coverage rates for their target populations. Overall, it is consistent with the literature that committees such as JCVI seem to be unduly burdened by the imperative to provide high-quality data justifications for *every* decision, without the resources necessary to easily manage a multi-phase, large-scale project like modelling they might use to provide that necessary justification. However burdened they may be, they achieve success in the majority of their outcomes (in this case, effective disease control and overall high rates of vaccination) by implementing solutions that are provisional and circumstantial, not by enacting fundamental reform of the governmental systems that generate the impossible bind, or “wicked problem”, of demanding the evaluation or generation of high-quality evidence without the allocation of resources for doing so (Head & Alford, 2013). Clearly, governmental systems that are inherently “complex” systems provide the context for the operation of the majority committees such as JCVI, and thus, this is identified as the third primary challenge to the effective and efficient use of modelling, and evidence more generally, to underpin policy decisions.

Beyond the difficulties of operations and evidence availability, the committee expressed concerns about its role in matters that have obvious ethical implications or dimensions and widespread social impact. Recent studies that JCVI might use to underpin decision-making about the costs and benefits of adding a new vaccine to the immunisation schedule account for some variables on an ethical dimension by integrating different quality of life indicators (Christensen, Hickman, Edmunds, & Trotter, 2013), but whether this is sufficient to assuage all involved stakeholder concerns remains an issue. JCVI does not seem to be fully comfortable with parameterising and integrating social impact or ethical dimensionality into its models as a matter of primary analysis, but there are clearly members on the committee who would favour this approach. This disparity in approaches can lead to protracted negotiations about the correct way to inform the model and which considerations are a public health priority. JCVI is mandated to consider a wide range of stakeholder perspectives and evidence sources to inform its policy recommendations. As this is unlikely to change in the foreseeable future, and thus, the high level of time and deliberative effort required by modelling in the context of the committee will likely remain fairly static.

2) How are policymakers using the models to inform their policies as deliberations progress in a natural setting?

Models are being used in a variety of ways as deliberations progress, however, they seem to be used in two primary modes: 1) To generate analysis about cost-effectiveness and immunisation coverage that justifies policy decisions about immunisation programmes, and 2) To explore impact and outcomes of possible policy decisions and explore parameters not included in “primary” analysis, such as social impacts and ethical dimensions of possible policy choices. Some of the uncertainty the committee express here stems from the characteristics of the models themselves and their lack of functionality that is well-suited to carry social impact information as a parameter in a way that is meaningful. Other concerns about scientific uncertainty seems more obvious, in that they stem from the data being used to parameterise the model being incomplete, uncertain, or in some cases, completely unavailable, and these concerns are consistent with modelling efforts in general, across model types (Riley, 2007).

However, some of the model use is questionable beyond a lack of sophistication with the methodology. When uncertainty exists in the cost-effectiveness data, there appears to be a trend toward creating multiple iterations of the model with increasingly wide ranges of possibilities (reflected in wider ranges of parameters) in order to manipulate the outcome of the model toward a favourable outcome. This allows JCVI to justify an action it has pre-ordained as desirable. This is also consistent with the literature, as such ethical use concerns are common to policy stakeholders and researchers that are at least partially reliant on modelling methods to underpin policies or predict possible outcomes, and recent literature addressing best practices for the use of dynamic models in these scenarios in order to mitigate these concerns (Pitman et al., 2012).

There also seems an overreliance on the model output as a “final destination” for evidence that JCVI can use to support its policy decisions, meaning model outputs are considered sine qua non of evidence-based policy deliberations, to the detriment of other forms of evidence. This is also less optimal use of modelling methods, as models they are in no way fully predictive of potential outcomes or capable of accounting for all critical variables, and should be used in tandem with a complete range of evidence sources, and not as the sole data-driver of policy decisions affecting the public. Additionally, best practices for modelling use in the healthcare scenario demands a high-level of model validation and public transparency about the validation process (Eddy et al., 2012); these are validation processes which would be difficult for the committee to maintain if they are over-reliant on the model itself to produce high-quality evidence. Predictive validity and external validity of the model are the most likely to be compromised if the modelling outcomes are not compared to “real world” data, and are instead treated as though they are central to the evidence deliberations.

Despite this deficit in use, it is clear that modelling plays a central role in the generation of data that allows JCVI to support its policy decisions, and that using modelling for these endeavours is often a good fit-for-purpose. Modelling is offering the policymakers the flexibility they need to keep up with the most current evidence and scenarios, changing data in the model parameters as they acquire new epidemiological data in real-time, which is a valuable asset. They don't always find the modelling iterations come to fruition quickly enough to provide the evidence they need to support their policy recommendations on short notice.

However, modelling in this context is offering a policy trade-off familiar to many such contemporary committees: it is a "lean" methodology that doesn't require many fiscal resources; significantly less than more traditional studies the committee could commission to examine these issues. The idea of "Lean" government is a relatively recent one, which is emerging as a response to traditional approaches to governance and policymaking, and aims at reducing the complexity and resource consumption in the public sector by reducing and compacting organizational structures and processes, while concurrently increasing the demand for technological innovation (Janssen & Estevez, 2013). Modelling methodology is an excellent fit into this paradigm, however, modelling is an exacting process for policymakers, and what they save in money, they lose in complex deliberations about parametrisation that would take up significant amounts of time.

3) Are modelling exercises used to directly inform the policy recommendations, (for instance, using the data they generate to directly justify decisions), or are they used in a more casually informative way? Is it possible to ascertain why they are used in this way by examining real-time use during decision-making deliberations?

The findings in this chapter suggest modelling in this context is not causally informative, and is, in fact, almost always being used to directly inform or justify the policy recommendations of JCVI. Even when modelling is being used for secondary analytical concerns, (for instance, when being used to gauge social impact of a particular policy choice), it is never framed as an exploratory exercise of note for later deliberations, but as a fundamental component of figuring out the best way for JCVI to proceed for the issue at hand. Models as used by JCVI used to ascertain coverage, safety and the potential for adverse events, the effects of potential programmes on specific (often vulnerable) populations, cost-effectiveness, epidemiological data, and the aforementioned social and ethical dimensions of policy choices; all of these are appropriate uses as suggested by the wider literature (Weinstein et al., 2001).

Upon close examination of the data and the resulting summary of findings in each cell of the matrix framework, most of the work that JCVI performs is data-driven. This means not only that evidence and data underpin the deliberations and decisions that JCVI makes, but that the actions of JCVI, and the committee's understanding of the current epidemiological situation is wholly dependent on a wide variety of data sets. The entire cycle of activity JCVI undertakes functions by the committee either acquiring, weighing or generating, evidence and data. Modelling as a way to both weigh (analyse) data and to generate data that justifies policy choices sits at the centre of this cycle of activity.

There are two primary reasons modelling is being used in this way during the policymaking process. The first is its availability: from experimental studies to systematic literature review, JCVI has been clear in its meetings that it is too under-resourced to employ more diverse or traditional methods of data generation or analytical reasoning, again, a commonality that might be found amongst governmental committees working in the new "Lean" environments (Janssen & Estevez, 2013). In lieu of the ability to perform a systematic review or cohort study and have that provide the basis for policy judgments, modelling provides the necessary "evidence-base" to account for the policy recommendations being made. The second reason for its central role in JCVI has less to do with the specifications of the individual model or the output of the model, but with the absolute imperative that all policy decisions and recommendations that are being made by JCVI be "data-driven". Since the need to develop policy with data is such a directly informative one, rather than using models in an exploratory fashion, models are almost always used in this context to provide some kind of analytic justification for action.

Yet, Despite some of the challenges present with such singular use of modelling methods in a policy setting, modelling does present opportunities to both underpin policy by providing excellent, partially predictive data for a given scenario, and to explore variables policy stakeholders know to be important, but are difficult to quantify (such as quality of life). Overall, the policymaking-modelling interface here, while sometimes fraught, is promising. Possibilities for leveraging this information to improve the use of evidence and modelling in similar scenarios, future directions for research, and limitations of this particular study are discussed in the following Conclusions section.

4.10 Conclusions

This study has successfully identified and characterised themes that describe the activity surrounding the use of scientific evidence generally, and modelling methodology specifically, to underpin public health policy. Primary challenges to public health policymakers in using methodology in these scenarios have also been identified: 1) time-pressure and operational resource limitation interfacing with the demands of systematic evaluation of evidence, 2) the conflict between scientific uncertainty and the need for transparency about that uncertainty with the public, 3) the complexity of the bureaucratic system in which the evidence is being evaluated, and 4) the lack of advanced expertise and confidence that policymakers have with the limitations and best practices of modelling use, particularly for the modelling that considers social or ethical impacts of policy decisions.

Identifying these challenges that are specific to public health policymaking, and the ways in which modelling methods are utilised in this setting, is itself a critical task. Applying strategic management principals to these operational deficit problems would likely provide at least provisional solutions to some of the more pressing challenges that JCVI and similar committees face. For instance, the provision of increased funding for expert modelling and scientific consultation when the committee is deliberating in crisis situations would serve to facilitate the necessary systematic approach to evidence evaluation.

This additional resourcing would result in higher-quality evidence evaluation and modelling exercises when time pressure is particularly demanding, and potentially increase positive health outcomes. Ancillary to that, increased interaction with expert modellers might increase the confidence that committee members have with the potential and limitations of modelling methods. This additional resourcing could be allocated on an ad hoc basis, so per annum funding remains relatively stable, and “Lean” operational objectives can still be achieved, bringing the needs of the committee and the needs of the larger organisation into better harmony. Future applied services research might explore some of the potential operational and strategic management solutions to facilitate public health policy committee functions in these complex bureaucratic contexts, as that information is woefully absent from the literature.

While the complexity of the governmental system itself is likely to remain a “wicked problem”, intractable and beyond the scope of committee functions, the competing demands of such a system could be more successfully addressed on an ad hoc basis if there were more explicit guidelines and best practices that provided a foundation to committee members and guided their deliberations. This is particularly true where the committee struggles with making command decisions in a climate of scientific uncertainty while simultaneously providing transparency about that uncertainty and the decision-making process to the public. Research that specifically addresses that interface in this context is key. While much research focuses on communication about vaccines and public confidence about safety, much less research focuses on how policymakers communicate uncertainty about these issues in a way that is both transparent and preserves the public trust, and what capacity building the policymaking bodies might need to develop in order to achieve this goal.

Finally, it is clear from the literature that precedes this data, and the findings from the qualitative analysis, that policymakers on such committees are 1) unlikely to be experts in the construction of models or the interpretation of their outputs, and 2) have limited terms of service and variable technical expertise. As the use of modelling in these scenarios is only likely to increase in future practice, providing the appropriate training to ensure that involved committee-members and policymakers have the necessary technical savvy to effectively use modelling methods is an imperative for the governmental agencies that oversee such committees. Barring this approach (since committee-members are term limited), ensuring that there is ample contact between policymakers and expert modellers would be a best practice for any such committee of this type.

4.11 Limitations of the Study

The general limitations of this study are largely methodological: the sample size is relatively small and the deliberations analysed are the product of one committee in the UK, and thus, caveats about how generalisable these findings are in more resource-limited settings apply. Sampling in the Framework approach to qualitative research is not able to fully represent to larger populations (i.e., all committees in public health) but serves to reduce highly complex descriptive data into meaningful themes in order to understand complex phenomena in health services research. The literature surrounding the use of evidence in policymaking is very large and constantly growing, and it would be an impossible task to review the entirety of research relevant to these inquiries. It is recognised that thus, this study is specific to a very limited point in time in the course of the evidence-driven policy agenda, and as political and social understanding grows, so does the meaningfulness of these findings. There is also the concern for this and future studies that, as research using these open access sources grows, policymakers will be less open and explicit in their deliberations when politically sensitive issues or scientifically contentious or uncertain topics come up. Ideally, increasing numbers of collaborations between policymakers and researchers will foster a climate of trust and openness in the future.

Chapter 5 – Extended Conclusions and Recommendations

5.1 Modelling and Evidence in Context

This thesis has addressed fundamental questions regarding how modelling methods can be used to unify literature about addressing epidemiological questions in a policy context, how the public confidence in modelling methods might impact upon their projected behaviours, and how modelling methods are used to inform the public health policy process. However the question of modelling as an emerging tool in public health and policymaking is one with complex intersections, unexplored applications, and an ever-increasing literature, and it is unlikely that any one single body of work can address these in their entirety. Thus, understanding modelling methods in context must be a continual effort, employing the talents of interdisciplinary teams of researchers, clinicians, and policymakers. As reflected by some of the evidence presented in this body of work, these methods are likely to become increasingly popular to underpin policies that directly affect the public health and well-being, so it also becomes an ethical imperative to educate the public about what the capabilities and limitations of models are and how they are used (O'Neill, 2004), particularly if we are interested in building the public's confidence in our recommendations that stem from model-based results.

Beyond the discussion of modelling methods specifically, this thesis also presents data and information that is pertinent to the use of evidence in public policy more generally. In this age of the evidence-driven policy paradigm, endeavours that seek to understand the use and perception of methodological tools that generate or evaluate evidence become increasingly important as they not only ensure that evidence is of the highest quality, but because they constitute contributions to our epistemological understanding of the scientific method (Scotland, 2012) and its use in non-scientific settings. Scientific inquiry as a way of understanding human phenomena demands we also include our methods in our systematic evaluation. Evidence is important, but the evidence we generate is only as reliable and valid as the methods we use to generate it, and this thesis adds to that fundamental understanding of how this increasingly popular method is being used, and challenged, in the settings of most public interest.

This chapter will present the broader conclusions from each of the three data-driven chapters that comprise the majority of this body of research. These conclusions will be framed in the context of addressing the deficits and leveraging the strengths identified in the findings and discovered in course of research, and will include recommendations to improve the use of modelling methods in the various scenarios presented in the chapters. These recommendations will be grounded in literature that encompasses process optimization, research development, strategic management, and organisational improvement, in order to assure that the recommendations themselves are based on evidence that reflects best practices in both research and policymaking settings. In the following section, that literature is briefly introduced and reviewed, in the interest of orientation and transparency.

5.2 Process Optimisation, Research Development, and Policymaking Management

In order to recommend best practices that address deficits in the use of modelling methods, an understanding of the foundational principles of organisational improvement, strategic management, and process optimisation research is of fundamental importance. Research-based policymaking is a process, and the adoption and meaningful use of emerging technology like modelling methodology fits into the study of optimising processes in organisational settings. Thusly, this section outlines the body of research that underpins the recommendations for more "meaningful use" of modelling methodology in this chapter of the thesis. Beginning in section 5.3, these principles are then applied to the findings of each data-driven chapter.

The notion of "meaningful-use" of healthcare technology stems from the provision of an American federal law that intends to address issues of whether technological innovations in healthcare management can actually improve the function of public health systems, and thus, healthcare outcomes (Hogan & Kissam, 2010). The meaningful use statute seeks to provide a framework for the evaluation of whether entities like Electronic Health Records (EHRs) are used in a way that actually improves the quality of healthcare provision, and encourages this meaningful use by creating incentives for the widespread implementation of EHRs (Hogan & Kissam, 2010). This framework is useful to consider in order to understand what "meaningful use" might mean for similar emerging technologies meant to improve the provision of healthcare delivery, such as modelling methods.

In order to dispense these incentives, the U.S. Department of Health and Human Services (HHS) set definitions of what constitutes "meaningful use" under these proposed regulations (Hogan & Kissam, 2010). In short, meaningful use seems to encompass two concepts related to the utilisation of the given technology in such a way that a) the use of the technology is being executed up to standards of good practice and b) that the use of the technology is contributing to measurable benefit to the public health (Hogan & Kissam, 2010). The idea of regulating the use of an electronic tool used to manage data in a healthcare setting is not without its pitfalls and controversies, however. Scientific researchers, policymakers, and other stakeholders may all have different standards by which to measure whether the adoption and use of EHRs (or any other technology in healthcare) is successful, and this lack of standardisation across organisations and disciplines can lead to challenges in tracking the progress of meaningful use (Hogan & Kissam, 2010).

In light of that lack of standardisation, what exactly is meant by "meaningful use" in this context could encompass a wide range of indicators and targets, and, in order for providers to glean the incentives provisioned in the meaningful use statute, the bar for success was set rather high by the Federal government (Jha, 2010), and some would argue, rather arbitrarily. The reasoning behind this challenging standard of excellence for the use of EHRs was in deference to data suggesting that the mere adoption of EHRs was an insufficient condition to improve health outcomes significantly, so policymakers involved in the development of the statute sought to ensure that the effective use of EHRs was based on scientific evidence supporting the benefits of various uses of EHRs to improve the quality of care (Jha, 2010).

As with EHRs, modelling methods are a technological tool used in healthcare policy settings with a substantial amount of potential to improve the quality of healthcare decision-making, and thus, improve overall healthcare processes and outcomes. Yet, systematic review of the literature reveals little effort to standardise or to establish best practices for the optimal use of modelling methods in healthcare and policymaking scenarios, let alone a movement that would incentivise researchers and policymakers working on healthcare issues to engage in said best practices. Granted, the extent of diffusion of this or any other popular technology across diverse policymaking and research settings would make independent oversight prohibitive, if not impossible. So while the idea of "meaningful use" as applied to modelling practice should be considered with a fair amount of caution, the idea that there is a single concept that might encompass both ideas of best practices in use and positive impact of use has translatable possibilities.

Despite the difficulties of measuring meaningful use, good scientific practice would dictate that since modelling methods have the potential to become the predominate method by which we generate and evaluate evidence for the purposes of public health policymaking, there should be some identifiable effort to evaluate the use of modelling methods and subject them to the same type of impact assessment as similar organisational tools in the healthcare setting, like EHRs. Prior to this thesis, it does not appear as though that specific effort has been made. This is likely due in large part to the fact that most people would view modelling methods solely in their role as a tool in the scientific or research methodological literature, and in fact, that is where the bulk of the (limited) evaluative research on these methods falls. However, this thesis presents significant evidence that strongly suggests that the optimal use of this method is highly context-dependent, and evaluative study of it should also be framed in the context of technological innovation in a policy setting.

A notable perspective from the health organisational management literature suggests findings that harmonise with the findings in this thesis: that one of the most significant elements of successful implementation of technology in the health policy setting is that of human behaviour and interaction, specifically the importance of knowledgeable and resourceful leadership and staff involved in the use of the technology, and overall high levels of participant buy-in to whatever technology is being introduced into the system (Buntin, Burke, Hoaglin, & Blumenthal, 2011). The parallels between the findings in this thesis and this perspective from organisational research continue in the call for further studies that document and outline the challenging aspects of implementing health information technology and also address solutions for these challenges more specifically (Buntin et al., 2011).

While the findings in this body of work represent a partial beginning to this endeavour, much work on the relationship of policymakers and systems to the technologies used to support healthcare decisions remains to be done. Buntin and colleagues note (2011) that directions for this type of research can benefit from the perspectives of the continuous quality improvement literature, and that themes that would yield needed data include: implementation strategies training needed before implementation begins, support while use is ongoing, and the possibility of unforeseen consequences of technology adoption.

Although these recommendations for exploration seem to speak to the needs of a contemporary healthcare system that seeks to improve the use of technology on the cutting edge, efforts to improve the function of the healthcare decision making and delivery systems are far from new. Elwyn et al., (2012) explain that over that last fifty years, a wide array of approaches have been taken to improve the quality of healthcare provision, and that many of them, such as professional education redesign, improvements in peer review, and the implementation of total quality management tools have produced some desirable, if not long-lasting, results. However, Elwyn and colleagues continue that none of these studies have fully addressed the intractability of many persistent challenges in the healthcare system that block the best use of decision-making tools, and thus, the provision of optimal care. As argued throughout this thesis, this is likely at least partially due to the convergence of problems that arise when interdisciplinary approaches to managing evidence-driven healthcare decision-making are neglected.

It remains important to note that this call toward increased process improvement or evaluation of methods being used in a policy setting is not uncomplicated. Evaluation itself is complex, and the outcome of an evaluation effort in policymaking settings would need to clearly communicate the underlying reasons why a particular technology or improvement protocol in the healthcare policy setting has or has not worked and would need to provide information for how any failures can be addressed (Parry, Carson-Stevens, Luff, McPherson, & Goldmann, 2013). Process improvement initiatives are often as complex and interdisciplinary as the systems they aim to improve, and the generalisability of the results of these evaluations can be limited if the evaluation doesn't consider both the independent qualities of the process it is examining as well as the context in which that process is occurring (Parry et al., 2013). To answer this, I argue for the adoption of formative, theory-driven evaluation. Parry et al. (2013) describe process improvement as iterative in nature, and highly variable depending on whether processes are at an emergent, innovative stage of development or are more widely disseminated. Again, this idea of context-dependence comes to the fore, and the outcomes of the evaluation of process improvement initiatives that seek to optimise the use of modelling methodologies in the policy environment would need to be highly dependent on which modelling environment or scenario was being examined.

Creating these context-sensitive recommendations for the optimal use of modelling methods in policy-organisational settings also requires consideration of evidence use in these settings more generally, and how those issues of evidence-use in general might reflect on the use of modelling. Although evidence-based policymaking shares an originating literature and body of research with evidence-based medicine, the randomised controlled trials and systematic reviews that evidence-based medicine mostly depends upon to provide its justifications for action many not provide a sufficient evidence foundation for the complexities of public health policy problems (Orton, Lloyd-Williams, Taylor-Robinson, O'Flaherty, & Capewell, 2011).

If the challenges of evidence-based policy are viewed as an issue of process optimisation, then the processes of evidence-based policymaking can be said to involve a series of steps: problem delineation or definition, the development of possible options for resolution, followed by the implementation of the policy (Orton et al., 2011). The types, quality, and quantity of evidence required at each of these steps can vary greatly, and thus, the evidence used in public health policymaking must addresses not just the question whether intervention is effective, but also issues that are less readily available in the research evidence, such as organisation, implementation and feasibility (Orton et al., 2011). This process improvement perspective, and an understanding of the challenges that come with use of evidence to underpin policies or initiatives as organisational, and not just a scientific problem, could greatly improve the use of modelling methodologies in both research and policymaking settings.

Now that a basic foundation has been established that provides a process-improvement and organisational development perspective on the use of evidence in policy, what follows in section 5.3 are general recommendations on the use of modelling for policy-relevant questions and in policymaking settings in a broad sense. Section 5.4 begins more specific recommendations for improved use of modelling methods on a chapter by chapter basis. The final subsection of the body of the thesis, 5.5, provides some suggestions for further research.

5.3 General Recommendations on the Improved Use of Modelling Methods

Currently, approaches to public health policies and programmes are largely based upon ecological models: perspectives that are the result of a convergence of ideas from various disciplines and fields of study including, but not necessarily limited to, those in sociology, biology, education, and psychology (Richard, Gauvin, & Raine, 2011). Within the framework of this approach, the current expectation for public health policy initiatives is that they will account for increasingly complex individual and environmental characteristics and variables, such as socioeconomic status, gender, sexual orientation, and level of education, that might impact upon the success of a given policy or initiative (Richard et al., 2011). Likewise, epidemiology as a field has begun to recognize the benefits of integrating these social and environmental factors into its traditionally more causal models (Richard et al., 2011). While this more inclusive approach to understanding public health problems is a sign of needed progress, psychosocial and ecological variables are themselves highly complex, and integrating them into modelling endeavours is not a straightforward process.

Joshua Epstein (2009) touches upon foundational issues in taking a more ecological or systems approach to all types of computational modelling relevant to epidemiological or health policy questions. Epstein notes that human behaviour has a profound effect on everything from disease transmission and progression to the success of vaccination or other behavioural change policies and interventions, and modelling human behaviour is a more complicated undertaking than one of simple information fitting. Epstein (2009) describes people as “prone to error, bias, fear and other foibles”, and while that may be circumstantially true, it is only relevant in modelling endeavours in so far as that “fear and bias” can be incorporated in a model in a meaningful way by using data drawn from the literature documenting measurable behaviours with measurable impact.

Epstein (2009) continues that the principal challenge for modelling is to represent such behavioural factors appropriately, and this body of research confirms this assertion. Funk, Salathé, & Jansen, (2010) note that predicting which actions people take to protect themselves during an epidemic is highly dependent on “temporal and societal context” and is likely difficult to parse and predict in the age of rapidly disseminating information and every-increasing connectedness. Funk et al., (2010) also point out that there are innovations in tracking human behaviours in real time using a variety of technological approaches, while noting that, despite these advances, that modelling exercises that seek to characterise or explore human behaviour on the transmission of infectious diseases were are often based on flimsy anecdotal evidence or the “common sense” of the modeller, often taking a game theory approach to rational behaviour in their models. Funk and colleagues (2010) continue that modelling exercises are “almost never validated with quantifiable observations.”

This lack of validation seems antithetical to Epstein’s (2009) call to appropriately inform models in order to get the most out of them, and Funk et al., (2010) note that there is a rich and substantive empirical literature that address the sociological, psychological and public health elements of human reactions to the presence of the disease, even if that knowledge is rarely applied to questions of how these elements affect disease dynamics in the context of models. For instance, Davis, Stephenson, Lohm, Waller, & Flowers, (2015) offer recent evidence addressing how members of the general population might respond to communication about risk during a pandemic event by adopting personal protection protocols like social isolation and hygiene. The authors explain that some of the resistance to behaviour change we perceive from the public could potentially be the result of concrete barriers (be them psychological or physical) in implementing the recommended actions.

Findings such as those in Davis et al., (2015) provide precisely the types of measurable human responses (and explanations for them) that inform the modelling exercises in Chapter 2, but too infrequently inform other modelling endeavours that seek to address the intersection of psycho-social and epidemiological issues. Because this area of modelling inquiry is likely to provide the type of information that policymakers exploring possible intervention recommendations and risk communication strategies would utilise, it's of central importance to make sure similarly high-quality information about human behaviour is used to parameterise a model in a policymaking setting.

Thus, a primary recommendation for improved modelling practice in policy-relevant scenarios is to discontinue modelling psycho-social constructs such as "fear" that cannot be measured or quantified in any way meaningful to the public interest, and to instead include quantifiable data about measurable behaviour such as whether people act upon the information that's relayed to them about protective actions and how effective the action is at preventing a given disease (Funk et al., 2010). Although human behaviour during a pandemic event can be exceptionally difficult to predict, a more systematic approach to the parameterisation of modelling exercises can lead to more sophisticated and useful outputs, and thus is strongly recommended.

Yet, it is not just the appropriate parameterisation of a model that matters. Determining whether a model reflects reality sufficiently to be predictive in any sense is also a major challenge. While modelling methods may be used to both explore the dynamics of pathogen transmission during an epidemic event and to predict the impact of an intervention upon an epidemic, it is worth reiterating that the extent and quality of available data with which to do so can be variable, and that the ideal of having timely, adequate data to integrate into the model isn't always achievable (Grassly & Fraser, 2008). Beyond parameterisation, model choice and design also impacts upon how successful a modelling endeavour is. In order to maintain their usability, interpretability, and accessibility, models should be kept relatively simple, but not so much so that they cannot reflect the complexities of the reality it is addressing (Grassly & Fraser, 2008) .

However, striking this balance between accessible simplicity and generalizable sophistication requires a balanced, even expert, approach to model design and choice, and a systematic approach to the processes by which the complexities in the model are chosen and integrated (Grassly & Fraser, 2008). As discussed in previous chapters of this thesis, this kind of expertise constitutes a highly technical skill, and the scenarios in which modelling exercises are being increasingly used don't necessarily ensure that an expert modeller is readily available. One modelling exercise to inform a public health policy could require, for instance, the input of a psychologist, a policy analyst, an epidemiologist, and an expert modeller in order to ensure that the model is not only built to the correct specifications of complexity or simplicity, but that the highest-quality psycho-social or epidemiological data is being chosen and interpreted into model parameters. It is thus a further recommendation that the design and choice of a model is considered as carefully as, and in conjunction with, the data that informs the model parameters.

As discussed in section 5.2, the "human element" can be pivotal to the success or failure of methodological use in a policymaking setting. The above recommendations all require that each member of the modelling team is able to meaningfully contribute to either model content or design, and ideally, that all members of the team are operating under experienced leadership and have a shared vision for the purpose, potential, and meaning of the modelling exercise. And while it is understood that such an ideal team in a committee setting is likely unrealistic, it is important to note that the properties of the policymaking team can play as critical a role in the success of a modelling endeavour as any feature of the model itself. In light of this, it is a recommendation that modelling or model interpretation that happens in a committee, research group, or other group policymaking setting is performed by an appropriately qualified and interdisciplinary team.

While the pitfalls of interactions between policymaking bodies and researchers include the coercion of research agendas to address policy questions, those issues are covered mire extensively in Chapter 4. Despite those possible complications of these relationships, there should be a move toward the deliberate creation of more interdisciplinary partnerships between modelling experts, policymakers, and researchers to specifically address these disciplinary intersections in the literature. These partnerships would ideally be continual exchanges, and not just circumstantial in nature. Established knowledge transfer relationships, or strategic alliances, are less likely to suffer from issues of undue influence or persuasion, and previous familiarity has been demonstrated to facilitate meaningful collaboration on problem solving tasks (Inkpen & Tsang, 2005).

In order to support the recommendation for these partnerships, it’s important to briefly consider the guidelines from the literature for fostering them. Collaborative, multi- and interdisciplinary relationships across fields can create competition between the aims of innovation and organizational knowledge transfer and the costs that arise from the effort of coordination and relationship development in these collaborations (Cummings, 2005). Costs can come in the form of developing new recruitment and retention initiatives to encourage and incentivise scientists to work on projects with policy implications and bear the operational weight of cross-organisational collaboration (Börner et al., 2010).

The management of scope in these collaborations requires significant coordination effort on behalf of all involved parties in order to achieve the most effective outcomes (Börner et al., 2010). Scope considerations range from the inter-organizational to the intersectional, with issues of geographical scale and analytic capability potentially further complicating matters (Börner et al., 2010). As the interdisciplinary teams engaged in these types of boundary-crossing initiatives often need to consider multiple levels of analysis, ranging from the molecular and clinical to the psycho-societal and political levels of policy analysis, spanning these “often-divergent worldviews” of science or translation to practice can often require its own translational expertise (Börner et al., 2010).

The ready availability of this expert translational opinion, access to systematic and critical literature review specific to purpose, and the lack of general resource support are additional concerns that can affect the use of modelling specifically, and evidence more generally, in a policymaking or research setting. This is particularly true of the use of modelling in governmental settings (such as we see in Chapter 4), and has been a common theme in the development of this research and the body of literature it reviews. Declines in funding for salary and training support for researchers and scientific experts in government or public sector policy settings can make these types of careers undesirable and prohibit talented candidates from applying or participating in these interdisciplinary teams (Moses III & Dorsey, 2012).

In the current austere environment, scientists and policymakers involved in the development of evidence-based policy often feel compelled to assume the responsibility of communicating the connection between public health and well-being and their policymaking and research activities to funders (Moses III & Dorsey, 2012). There are additional expectations of policy stakeholders and scientists operating in a resource limited environment as they are asked to accomplish more with less resources. For instance, many decisions about the best treatments and interventions must also be weighed against the cost-effectiveness or operational feasibility of the various policy options, a situation where clinical or scientific judgment about health could take a backseat to concerns like short-term economic stability or logistics concerns (Moses III & Dorsey, 2012).

As economic austerity is likely to continue unabated in settings where models are being used to support policy decisions, it is important to consider the possibility of alternative options for funding and research support (Moses III & Dorsey, 2012). Public-private collaborations and partnerships with non-profits and public interest groups are possible, and perhaps in some circumstances such as basic biomedical research, even desirable, but they present the opportunity for conflicts of interest and undue influence that could serve to further complicate an already complex policymaking scenario (Moses III & Dorsey, 2012).

Due to the possibility that a public-private funding interface can cause ethical conflicts, instead of immediately resorting to outside sources of funding, the recommendation here is increased attention to and explicit documentation of how the lack of resource support from the original funding body directly impacts upon the use of modelling methods or other forms of evidence in the policymaking process. This should be done with a view to redoubling lobbying efforts for ad hoc funding. While it may be unreasonable to expect increased overall annual budgets for advisory committees from the government or national health services, it is much more realistic to assume that a committee could secure ad hoc funding from its governing body if it can submit a detailed, itemised proposal for costing out a modelling exercise (Prowle & Harradine, 2014). However, providing and defending this itemisation depends on the committee or group understanding exactly what is entailed in executing a successful modelling endeavour, including cost.

Thus far, this section has offered general recommendations on the appropriate approaches to integrating data from behavioural, observational, or experimental studies into the parameters of modelling exercises, the role of proper design of modelling exercises, the role of multidisciplinary teams in policymaking underpinned by modelling, and the provision of operational support for modelling endeavours. The final general recommendation made here applies not to the modelling endeavour itself, but rather to the literature, or lack of it, surrounding the use of modelling methods in policy settings.

In order to successfully implement any of the above recommendations that might improve the use of modelling, a larger knowledge base addressing the aforementioned issues of parametrisation, model choice, and the operational needs of modelling exercises is necessary to guide policymakers and research teams so that they may begin to create best practice standards for modelling use. As of this writing, no unifying literature that describes challenges during implementation of modelling use in policymaking or provides guidelines or standards for use exists. While this thesis is by no means comprehensive or exhaustive, it does seek to provide a starting point for more unified discussion around the development of standards of practice for modelling methods.

The development of these standards is important because the expectations of performance for modelling methods are increasing in proportion to their growing popularity for approaching entrenched problems that exist in complex policy systems (Homer & Hirsch, 2006). The expectation of modelling in this contemporary paradigm is that modelling methods will be able to functionally integrate the highly multivariate data that comes with the prevailing ecological approach to public health problems, which includes “disease outcomes, health and risk behaviours, environmental factors, and health-related resources and delivery systems” (Homer & Hirsch, 2006). While this “system dynamics” approach to modelling does indeed show promise as a means to create more encompassing models that are more accurately predictive, the growth of the modelling method is likely to be stymied by the challenges that this thesis describes if there is no concerted effort to address them.

What follows in the next section is discussion that addresses the findings of each of the data-driven chapters in the context of the more general recommendations about optimising modelling use that appear above, but with more specific focus on the particular challenges that are identified in the findings particular to that chapter.

5.4 Extended Chapter Conclusions and Recommendations for Improvement

In this section, the specific issues that each study’s findings present are addressed, and recommendations to approach these issues are outlined. While there is considerable overlap between these studies regarding some of the challenges that have already been identified in the section prior, there are many elements from the findings of each study that warrant individual consideration and a more targeted approach to the formulation of recommendations for improved practice. Similarly, each individual study includes a conclusions and discussion section that serves to crystallise findings in a more traditional manner, and those issues may also appear here. However, this section serves to draw out individual findings for the purpose of considering ways to address challenges more contextually than a traditional discussion section. This section begins with Chapter 2 and concludes with Chapter 4. In the final section of the chapter, a few brief suggestions for future research directions are given.

Chapter 2: Modelling Infectious Disease for Pandemic Planning: How do non-pharmaceutical interventions and disease severity affect epidemiological dynamics?

It is important to preface the extended discussion of this particular exercise by noting that it was not solely designed and executed to answer its primary research questions. Because the question of whether technical expertise in modelling methodologies is central to the success of a given modelling endeavour recurs multiple times in this thesis, it is important to disclose that I am not an expert modeller, and came to this research by way of more traditional public health training, grounded in an interdisciplinary social science background. Thus, there is a meta-evaluative aspect to the exercises in this chapter.

As this thesis developed, it became obvious that I would personally grapple with many of the issues of technical expertise, modelling design, parameterisation, and generalisation of findings that I was researching and documenting. In light of that information, and in the spirit of lending qualitative depth to the experience of the development of this body of research, I begin this section by briefly describing the challenges and successes experienced in completing this particular study, and how I think those experiences fit into the context of the literature on modelling that appears in subsequent chapters of the thesis. I split this discussion between the following two paragraphs. In the first, I describe the challenges faced as a non-expert modeller and how I sought to resolve them. In the second, I explain how I leveraged my previous experience and training in order to successfully use the model to generate data that addressed my policy-relevant research questions. After those two paragraphs, the discussion moves to the actual model findings and recommendations to address the issues those findings revealed.

1) <u>Challenges approaching the modelling process</u>: With no previous expertise or experience in computational epidemiological modelling, the most significant barrier I faced was the deficit in my technical modelling skillset. This type of modelling requires an understanding of the structure and function of the ordinary differential equations that constitute the model itself, the ability to parameterise the terms in that model appropriately,

and the ability to translate that model into code in a given programming language to use a computational platform to solve the differential equations. I was able to find substantial amounts of information regarding the basics of executing these tasks in the robust online communities that have grown up around the various programming languages available, but was given guidance as to where to look, information other non-experts are unlikely to have. Supervised by an interdisciplinary team, some of whom did have expertise in modelling, I was able to learn the basic, necessary skills over time; a substantially longer time period than a policymaker would have to complete such a task. This was a situation that, while suitable for research supervision, would be less than ideal in the context of a policymaking setting. I found that the challenges I encountered harmonised with those I drew from the literature.

2) <u>Advantages to approaching the modelling process as a non-expert</u>: As mentioned above, one of the technical skills necessary to complete the modelling scenarios presented in Chapter 2 is the ability to appropriately choose parameter values for the modelling scenario. In order to focus the model on an epidemiological question of policy relevance it is necessary to know how to draw from an array of multidisciplinary literature in order to appropriately inform the model, this was a task for which training across multiple social science and public health disciplines was of assistance. Having an "outsider" perspective on modelling methods also advantaged the process of informing the model in that I was able to decide upon which aspects of disease transmission and behaviour change to focus without being unduly influenced by preconceptions of what an epidemiological model of this type would typically look like and how it would be parameterised. This observation was also reflected in the previously reviewed literature on the importance of interdisciplinary perspectives and ecological approaches to ensure good quality modelling. Now that the necessary subjective research processes relevant to this chapter have been noted, the next paragraph will begin our review of the findings and recommendations for approaches to address the challenges therein.

The influenza pandemic that killed an estimated 20 to 40 million people in 1918 (N. Cox, 2003) looms over much of the public health inquiry and practice that addresses influenza in the contemporary paradigm. This is not merely because it represents an historical artefact of note, but due to the possibility that a similarly destructive influenza pathogen could emerge in the immediate future and cause similarly substantial morbidity and mortality (Khanna, Kumar, Choudhary, Kumar, & Vijayan, 2008). It follows then that much of the current research on influenza might be focused on the prevention of such an occurrence, either through improved surveillance or other control measures.

However, because of the possibility that control measures will be insufficient, and a serious pandemic event will eventually ensue (Khanna et al., 2008), it is also important to focus on issues of pandemic planning in the case of such an event. Thus, the modelling exercises in Chapter 2 are aimed not only at understanding how traditional epidemiological factors like routes of transmission and clinical severity might impact the spread of disease and possible burden on healthcare delivery, but on how the measures taken during a pandemic might help, or fail, to mitigate the impact that said disease will have on a given population.

With that in mind, the first notable finding worth further consideration from Chapter 2 intersects with the issues of parameterisation and data availability outlined in previous sections. The outcome of any modelling endeavour is obviously highly dependent on the data values used to parameterise it, and those values are most often to be found in the scientific peer-reviewed literature. In Chapter 2, both the assumptions about transmission and clinical severity (model 1) and the assumptions about handwashing, its frequency in the general population, and its efficacy (model 2) are based on a review of the virological, clinical, and behavioural literatures, and drawn from a range of epidemiological, experimental, and observational studies.

The idea that these parameters arose from a range of possible values within a larger body of literature is important: this means there is a possible range of outcomes depending on how those values are calculated. For instance, in our Chapter 2 modelling scenario, there is no one answer to how efficacious handwashing is in the prevention of onward transmission of influenza (Snyder, 2010b), but yet, the parameterisation of ϕ is not arbitrary. Although we don't know exactly how big the effect of handwashing is (because there is no experimental literature that gives us this exact value), we know two things: that the value of handwashing is greater than 0 and less than 1 (Grayson et al., 2009), and that it is anchored to how many people are actually performing the task during a pandemic threat event (Jones & Salathé, 2009a). For instance, even if the efficacy of handwashing was 1, if only a few people are performing it regularly, its effect on onward transmission would be diminished. Conversely, if the actual value for handwashing efficacy is closer to zero, if the frequency of handwashing is high and it is a widely adopted behaviour, we may expect to see some cumulative effect on disease transmission dynamics. So, if we know from the behavioural literature that handwashing is a relatively easy to adopt and popular activity amongst the public in response to infection risk, and we know handwashing has some effect, we can calculate a value for ϕ (the effectiveness of handwashing x the frequency of handwashing), even though we are lacking a precise value from experimental studies.

This example is important because, even though there is often a robust literature on any given parameter of interest, even though systematic review may be performed, that literature will very rarely offer up a single, definitive value for use in the model (Fone et al., 2003). Therefore, the expectation amongst modelling teams should always be that there is likely to be a range of potential values that could be explored, and that subsequently, there will be a range of possible outcomes. Understanding the relationships between values that may come from disparate literatures (for instance, in our example, the question of handwashing efficacy is drawn from the virological experimental literature, and the question of handwashing frequency comes from the behavioural and risk communication literature) is fundamentally important. Thus, a recommendation from Chapter 2 would be that any standard of practice would strongly urge transparency about the certainty of values and their origins when using models to underpin policy. Clarity about how those ranges are calculated, where they come from, how certain they are, and how the range of certainty might influence modelling outcomes is a matter of fostering public trust, and can also protect policymakers if the policy efforts underpinned by the modelling outcomes fail (O'Malley, Rainford, & Thompson, 2009).

Further to these issues, modelling-policy teams working on the types of epidemiological and intervention questions like we see Chapter 2 need to be aware of the possibilities of unintended, and unexpected, outcomes. Even when the parameters, or parameter estimates, being used in the model seem conservative or well-founded, and the range of outcomes are anticipated to fall into a known range of options, the modelling-policy team should be prepared for some results to be counter-intuitive. For instance, from our Chapter 2, model 2 handwashing example, we see that the same number of people overall get sick throughout the course of our epidemic, but slightly more are infected with severe disease than in the previous model. This outcome is obviously dependent on the interaction between all parameters, but the addition of a non-pharmaceutical intervention was not anticipated to result in overall higher rates of severe disease in our model.

Yet, it follows that when parameter values are uncertain due to a lack of conclusive information or are chosen on an ad hoc basis, it cannot be said with certainty that the interactions in the model are a strong approximation to the disease dynamics in the real world (Goeyvaerts et al., 2015). This is true in a general sense of all models, but it becomes a more urgent consideration with uncertain parameter values. In consideration of the high-stakes involved in designing a public health policy based on outcomes from modelling scenarios that include uncertain ranges of parameters, it is important that this aspect of these epidemiological modelling exercises is more fully explored. These unexpected outcomes, and questions of how closely models are even able to approximate real world phenomena, should both be further characterised in the literature and as a part of best practices guidance in any move toward standards of practice for modelling into inform public health policy. It is additionally recommended that there be some effort to educate modelling-policy teams on the risks they are assuming in basing public policies or communications about risk on modelling exercises when those exercises are based on uncertain values.

The final finding of note from Chapter 2 relates to the lack of impact found from handwashing behaviour. Clearly, it's notable on its own that handwashing doesn't significantly reduce mild disease in the expected quantity, and the increase of severe cases is also of note. But in the context of the literature surrounding behaviour change during pandemics, it becomes a particularly meaningful finding, and an important point of consideration when deliberating appropriate standards of practice for modelling in policy settings. Hand-hygiene was selected as the behavioural proxy of choice in the model because it is so widely studied, and the one of the most recommended and adopted personal protective behaviour during outbreaks of influenza (Rubin et al., 2009; Updegraff, Emanuel, Gallagher, & Steinman, 2011).

Concurrently, there has been a significant amount of time and resources spent on targeting risk communications so that people will continue to adopt behaviours like handwashing when they are recommended by public health entities (Reynolds & Quinn Crouse, 2008). But this relationship is confounded by the fact that there's little concrete evidence to suggest that handwashing is optimally effective at preventing influenza transmission or infection, and in fact, there has been contention that handwashing has no meaningful efficacy against influenza at all (A. E. Aiello et al., 2010; Biran et al., 2009; Grayson et al., 2009; Snyder, 2010b). When we consider that the virological and epidemiological literature is inconclusive on handwashing efficacy, and our Chapter 2 findings suggest that hand hygiene may not have any substantive effect on outcome indictors anchored to pandemic planning, it is important to explore the question of allocating additional resources on risk communication that promotes an as-of-yet unconfirmed method of personal protective health behaviour as the most effective.

One answer is that the epidemiological community is overly invested in the research that suggests handwashing is a health behaviour that is easy to persuade the public to adopt and has few concrete barriers. Its ease of use is an attractive feature in any intervention, and it appears reasonable to continue to aggressively promote a health behaviour that is known to have scientifically-established benefits for preventing infection and onward transmission with other serious pathogens (Edmonds et al., 2013). An alternative explanation is that the individuals and institutions responsible for the promotion of hand hygiene are typically housed in policy settings, and may be unaware that the efficacy of hand-hygiene for the prevention of influenza is still scientifically questionable. If this is the case, it is likely the natural result of scientific "siloing", wherein individuals working on the same problem from different disciplinary perspectives are unaware of what developments are being made on the problem in a different discipline, and this is particularly true in a situation where information diffusion is happening across organisational types (Green, Ottoson, Garcia, & Robert, 2009).

As suggested in the previous subsection of more general recommendations, proactive creation and maintenance of interdisciplinary teams focused on epidemiological modelling problems may help ameliorate this problem. But, more specific to the findings in Chapter 2, a more robust understanding of the nature of scientific uncertainty and how it functions in modelling-based decision making is necessary amongst all stakeholders involved in the process of using models to answer policy-relevant epidemiological questions (Walker et al., 2003). It is the final recommendation from Chapter 2 that issues of scientific uncertainty, and the ethics of risk communication and health communication in the context of scientific uncertainty, be at the fore of any standards of modelling use in the policy setting.

Chapter 3: How does the use of contemporary modelling tools to produce public health policy influence the public's projected health behaviour?

Chapter 3 of this thesis presents evidence suggesting that the public confidence in modelling methods to underpin public policy, and to inform recommendations about their projected health behaviours, could be improved. It also suggests that the public is most likely to respond more favourably to evidence generated by traditional experimental methods, which, due to their high-resource demand and lack of suitability for some policy problems, are unlikely to be the predominate form of evidence that informs how we make recommendations to the public about their health behaviour. This chapter section presents an extended discussion of communication and educational strategies that could be employed to ensure that the public has increased knowledge of, and confidence in, the role of modelling methods in policy development and research.

As previously stated at the end of Chapter 3, these public education and communication objectives could be achieved in a variety of ways, including, but not limited to, a change in science curricula and pedagogical approaches, increased attention to how policy recommendations that request behaviour change are communicated to the public when those recommendations are based off of model-generated evidence, (including protocols for strategic communication); and improved communication between the media and the scientific-policy community to ensure modelling methodology is accurately represented as a standard methodological tool that is accepted by the research and policy communities as an integral part of good scientific practice. What follows is a discussion of all of these aforementioned strategies in the context of modelling.

Since the findings in Chapter 3 echo the literature suggesting that the adoption of emerging research technologies and tools like modelling methods require public confidence in order to be successful, (Slovic, Flynn, & Kunreuther, 2013) the first strategy suggested here is aimed at addressing how models are discussed and described in formal and informal learning environments. Gaining public confidence requires the public achieve a certain level of comfort, knowledge of, and familiarity with the proposed technology, concept, or method (Stocklmayer, Rennie, & Gilbert, 2010).

Typically, the process of instilling that kind of familiarity and engendering comfort with an emerging scientific concept or technology would be undertaken by integrating the target information into the curriculum of a formal educational environment, like a school (Stocklmayer et al., 2010). However, more contemporary approaches also favour knowledge transfer about scientific concepts in informal settings outside of traditional schools, such as in work settings or casual conversational settings within the community context (Stocklmayer et al., 2010). The assumption may be that the best place to approach the issue of educating the public about how modelling methods work is in a traditional school environment, but that might not necessarily be the case, as many young learners in particular can be highly critical of formal learning environments (Stocklmayer et al., 2010). A key strategy to ensure learners engage with the scientific concept you're promoting across learning environments is to relate the new concept to something they perceive as currently relevant to their day-to-day life experiences (Stocklmayer et al., 2010).

With that strategy in mind, it would be advantageous to develop learning objectives about models by leveraging the public confidence in a concept with which they are already familiar and feel is relevant to their current health behaviours: scientific experiments. The data in Chapter 3 suggests that the public is most confident in the data generated by scientific experiments and are most likely to project they will change their behaviour in the future if the evidence used to support that recommendation has been generated experimentally.

So, demonstrating how modelling parameters in public health are informed by the types of data with which they already hold in high regard (experiments, observational studies, and epidemiological data, for instance), might create a useful cognitive inroad to creating more positivity in the public perception around the quality of evidence generated by modelling methodology. Current research on the psychological effects of familiarity suggest that it is possible to mitigate negative perceptions of modelling if it's relatable to something already familiar: for instance, if models are introduced in learning environments as programs that process the kind of information the public is already comfortable with, modelling methods may benefit from a kind of "halo effect" surrounding the public perception of scientific certainty attached to experimentally-generated data (Mariconda & Lurati, 2015).

While the importance of transparency about the role of modelling when proposing policies has already been discussed in the extended discussion on Chapter 2, transparency and communication about modelling in the context of these Chapter 3 findings pivot not on political concerns, but on psychological ones. For instance, an increase in organisational behaviours that increase transparency, or even just give the appearance of increased transparency, engenders greater trust from the public in that organisation (Norman, Avolio, & Luthans, 2010). It logically follows that increased transparency around the parameterisation of models, clarity on outcome uncertainty from models, and openness about the challenges of modelling use in policy settings have the potential to increase the public's trust in a given organisation's activities. But beyond issues of trust, there is additional evidence to suggest that increased transparency can also increase the public perception of organisational and leadership effectiveness (Norman et al., 2010), a perception that is not without benefits when seeking to glean public support for public policies underpinned by modelling exercises.

All of the above strategies and approaches, save the discussion about organisational transparency, pivot on the idea of increasing public competencies surrounding scientific learning and modelling methods. The following discussion aims to discuss strategies for building the communication capacity of organisations and entities that are responsible for addressing the public on the matter of policies or behaviour change recommendations that are underpinned by modelling methods. One recommended strategy to approach the communication of risk or policy information to the public in a way that may increase confidence in modelling is by enhancing the relevance the health information within the message by specifically targeting the message to a given audience, as evidence suggests that tailored messages appear to stimulate greater cognitive activity than do messages that are not tailored to the specific audience (Kreuter & Wray, 2003).

It is important to note that, when considering new health communication strategies that could increase the public confidence in modelling, that deficits in public knowledge are rarely the fundamental driver of societal conflict over scientific or health information, and in fact, science literacy likely plays a rather limited role in informing public perceptions and decisions about scientific ideas (Nisbet & Scheufele, 2009). So, despite the importance of educating the public about models as a standard part of good scientific practice, resistance to behaviour change policies or risk communication may not be a result of ignorance about modelling methods or the underlying science, but rather a result of conflicting values or perception of authority (Nisbet & Scheufele, 2009). This is also partially borne out in the data generated in Chapter 3, as respondents reported having more confidence in the advice or opinions of scientific experts than in modelling methods. The public bias toward expert opinion and deference to "personal expertise" is well-established in the literature (Brossard & Nisbet, 2006), and reflected in Chapter 3 findings, but how scientific literacy about modelling methods might mitigate these communicator effects is unclear.

This demonstrates the importance of combining efforts at education about models with communication that is more persuasive than instructive, for optimal effect. Any standard of practice for the use of modelling methods should account for the need to design curricula for the public for use in both formal settings and more informal ones, such as science museums, and to design communication about modelling and modelling findings that is persuasive and strategic, rather than messaging designed to fill some perceived "information deficit". It would also be important to note that education about, and communication about, modelling methods should be treated mutually exclusively.

The findings in Chapter 3 were aimed at characterising a phenomena that has been more extensively studied in other domains: it is well-known that the public perception of scientific information can play a role in health behaviour. However, this was the first known attempt to gauge how that relationship works in terms of scientific methodology specifically, and served as a proof-of-concept that confidence in scientific methods, and not just trust in scientists, might in some ways mediate public health behaviour in response to policy recommendations. With that, it is also important to note that while this endeavour identifies a possible phenomenon, the sample size of these studies is geographically and size limited, which makes it prudent to exercise caution when generalizing the results and conclusions.

One of the limitations of the study may be the brief nature of the qualitative inquiry. Short answer mini-interviews as they appear in the Chapter 4 study may be sufficient to place respondents on a continuum of understanding when using a pre-existing framework or building upon one, but longer, more detailed interviews would allow this phenomena to be more completely characterised, and in fact, may help to provide the foundation for a scholarly literature that looks specifically at how the public's confidence with scientific methods specifically moderates their behaviour or support for scientifically underpinned policies. It is strongly suggested that when exploring this topic, mixed methods continue to be used. Despite the small sample size and brevity of the qualitative interviews, the questionnaire responses and qualitative data *in tandem* strongly suggest a critical route of inquiry, and the methodological foundation for that inquiry should continue to reflect the complexity of the phenomenon.

Finally, this chapter examines public understanding of science in the context of climate change and infectious disease policy and recommended behaviours for such. These policy scenarios were of interest for several reasons: the amount of political and research funding for both is currently quite impressive, and the coverage of both issues in the mass news media raises the salience of these issues in the policymaker and public consciousness. More specifically, these two scenarios were also selected because they both are fields where the use of modelling methods is rapidly increasing, and the use of more traditional methods of inquiry are being augmented or even replaced with new research technology.

They were also selected due to a juxtaposition: climate change research and reporting is often related in the news media and policy recommendation with “models, whereas this isn’t as frequently the case with reporting on infectious disease; and this despite the fact that modelling method are roughly as common in both fields of academic and policymaking inquiry. My desire as a researcher was to look at the perception of the methodology both in a context where it may be familiar to the public and where it may not. It is thus recommended that efforts to explore this phenomenon look at each domain of inquiry as a separate entity, and understand the public perception of modelling in one domain may not translate to the next.

Chapter 4: The Evidence-Based Policy Agenda and Policymaker Relationship to Scientific Evidence

Although the study in Chapter 4 is presented as the last data-driven chapter in this thesis, in many ways, it sits at the very centre of the issues this thesis seeks to address. Primary challenges to public health policymakers when using modelling methodology in high-stakes, low-resource, time-sensitive contexts are often neglected or poorly understood by researchers. Yet challenges like these can play a central role in policies that can impact the well-being of entire populations of people, and as such, should be the cornerstone of any standard of practice for the use of modelling methods in such settings.

The primary findings from Chapter 4 allowed us to identified four primary challenges for the use of modelling the policy setting: 1) time-pressure and operational resource limitation interfacing with the demands of systematic evaluation of evidence, 2) the conflict between scientific uncertainty and the need for transparency about that uncertainty with the public, 3) the complexity of the bureaucratic system in which the evidence is being evaluated, and 4) the lack of advanced expertise and confidence that policymakers have with the limitations and best practices of modelling use, particularly for the modelling that considers social or ethical impacts of policy decisions.

These issues, and some possible strategies for resolving them, have been discussed in previous sections of this chapter. Noting this, this section will address the seemingly intractable nature of these issues, contextualising this thesis as a whole by using the literature on complex adaptive and sociotechnical systems, and “wicked problems” in public administration, to more completely characterise the underlying reasons for the entrenchment of the identified challenges in the use of modelling methods. Further, literature illustrating some of the strategies that can be employed to better understand evidence-informed policymaking as a complex system is introduced and discussed. In the final subsection, some future directions for research conclude the thesis proper.

Evidence-based policymaking can be identified as a socio-technical system, with the technical work processes of policymaking itself, and the social systems that constitute the working environment, interacting to create the overall system of interest (Westbrook et al., 2007). The constituent parts of the social system may include employees, managers, and contractors and their behaviours, activities, skills, attitudes and beliefs; while the technical aspects of the system might encompass the tools, devices, materials, and techniques that are used to accomplish the tasks in which the work is performed (Westbrook et al., 2007). The overall performance of an organization can be said to be functioning optimally if both sides of these equation are working in a balanced fashion, although it should be noted that what constitutes optimal function or balance is likely to be subject to the perspective of the individual or entity making such a determination.

Westbrook et al., (2007) state that sociotechnical organizational design theory is particularly relevant to the understanding of wicked problems in contemporary healthcare delivery systems. The authors continue that sociotechnical theory predicts that the introduction of a new tool (computational modelling methods, for instance) into a complex organization is “unlikely to bring immediate benefits without careful investigation of, and responses to, the impact on other technical and social subsystem elements” (Westbrook et al., 2007, pg.747). This is why, beyond generating data surrounding the use of modelling within this system, it is important to consider nature of the system itself when an attempt to develop standards of best practice for these tools is made. In short, the issues within the practice of modelling in policy settings cannot be addressed without understanding the problems of the policy setting itself.

The primary functions of large governmental health organizations involve increased pressures for efficiency and improved performance in the design and implementation of policies and social services which are responsive to the needs of a great diversity of individuals and communities (Albury, 2010). This is an exceptionally challenging charge, and a scenario which frequently gives rise to “wicked problems” that are characterised by their overly complex, intractable, and unpredictable nature, and their general resistance to solutions that might be applicable elsewhere (B. W. Head & Alford, 2013). Many of the challenges facing policymakers and researchers working to use modelling methods to develop policy solutions, such as time pressure with limited resources, or the tension between scientific uncertainty and the need for transparency, could easily be defined by their "wickedness". Likewise, some of the solutions proposed in this thesis to address them may be similarly stymied by these deeply entrenched problems elsewhere in the public administrative system.

To understand the wicked problem space, it is important to conceptualise of public policy challenges as overlapping and interconnected subsets of problems that exist across policy domains, levels of government, and hierarchies, both within and between organizations and political jurisdictions (Weber & Khademian, 2008). This is important to the modelling-policy interface as the committees, planners, and interdisciplinary teams at this interface often sit at the intersections of these domains, jurisdictions, and organisations, with funding, staffing, and oversight split between them (Weber & Khademian, 2008). This interdependency means that wicked problems are necessarily connected to other problems, which is why an issue like economic development or pharmaceutical manufacturing or import regulation could disrupt the use of modelling methods to address a problem like the introduction of a new vaccine to the immunisation schedule.

However, as Head and Alford (2013) explain, there are degrees and dimensions of "wickedness," and the problems that affect the policy-modelling interface may be more responsive to proposed solutions if those solutions are implemented with an understanding of the characteristics that make them singularly challenging. Head and Alford (2013) continue that targeted, partial, provisional solutions are more likely to produce results in this scenario than more holistic or encompassing proposals, as most of these wicked problems are relatively unique in comparison to other issues that arise in these settings.

Wicked problems are often the result of chronic policy and organisational failures (Ferlie, Fitzgerald, McGivern, Dopson, & Bennett, 2011) which are aided and abetted by the very nature and structure of traditionally hierarchical government. Ferlie et al., (2011) describe increased "fragmentation" of governmental entities after major reform and austerity measures have "hollowed out" the state, and note that these types of environments provide the needed climate for the growth of wicked problems.

There is some evidence to suggest that, in the UK, there is a shift toward models of a more "networked" style of governmental agency and organisation, (such as the National Health Service) and that these types of government organisations are more readily able to extend their function beyond the scope of any one agency in order to initiate a cross-boundary, collective response to a given issue (Ferlie et al., 2011). Given the extent to which collaborative and interdisciplinary effort has been highlighted in the literature and in these findings as central to the success of modelling methods in policy settings, it would be prudent for anyone wishing to optimise this process to attend to the various ways in which cross-cutting organisational capacity and structure can contribute to entrenching or resolving a barrier to performance.

Confronting and managing such deeply entrenched problems in a complex system requires the ability to draw upon a large knowledge base, and the understanding that the effective transfer, receipt, and integration of this knowledge will require consistent and ongoing effort in an environment where the teams of people managing the problem are likely to change long before the problem itself is resolved, even partially (Weber & Khademian, 2008). In fact, it is possible there are no complete solutions to these wicked problems, as they are the natural result of the interdependencies in the complex adaptive sociotechnical systems; but even if this is the case, it makes the argument for evidence-based, data-driven standards for practice for the use of tools like modelling methodology that much more important. Wicked problems, like those that occur in the process of modelling and the policymaking contexts in which modelling happens, do not have "right" or "wrong" solutions, but rather the possible outcomes of management efforts exist on a continuum of "good" and "bad" (Wexler, 2009), and the level of success of those outcomes is dependent whose perspective is being considered.

Modelling methods present the whole of human society with a powerful tool with which to generate meaningful evidence for action, and an exciting innovation with which to evaluate policy options for some of our most urgent and burdensome social and public health problems. But the use of such a high-impact methodology should be supported by the most robust guidelines possible and the highest standards of practice to achieve the best possible outcomes for the human populations those policies affect. While it is unlikely that there are overarching solutions for modelling problems specifically, and the wicked problems of policy more generally, this thesis makes a significant contribution to the data needed to address the dimensions of modelling practice that could make a difference in how policy is created and implemented. What follows in the final section are some suggestions for further research that will assist policymakers, researchers, and other involved stakeholders make the most of modelling methods.

5.5 Future Directions for Research and Practice

Each chapter of this thesis addresses different aspects of modelling use for policymaking and public planning. Covered here are topics ranging from the actual use and parameterisation of modelling methods in a pandemic planning scenario, to understanding the public perception of modelling methods and public willingness to undertake behaviour-change recommendations that come from modelling exercises, concluding with an in-depth qualitative exploration of the challenges and uses of these models in a real-world policymaking setting.

This data was generated in the hope of addressing deficits in the existing literature that prohibit a more complete understanding of how to improve the quality of modelling use in decision-making, and thus, the outcomes of policies. The scope of such an undertaking prevents exhaustive or comprehensive coverage of all research in the multiple fields and disciplines of interest, but in the course of conducting this research, several areas were identified where knowledge gaps in the literature prohibited more complete answers from being constructed.

In the epidemiological, virological, and clinical literature, there is a notable lack of literature on the efficacy of handwashing protocols for the prevention of respiratory diseases, especially influenza. This may be because there has been a perceptual extrapolation of efficacy to influenza from studies using gastrointestinal pathogens that confirm handwashing prevents infection and transmission in those scenarios. It may also be because there is mounting pressure to recommend interventions that are easy to persuade people to do and that have a low-cost imprint on government prevention and planning budgets. Whatever the reason, the literature on handwashing efficacy for respiratory pathogens, so critical to informing a high-quality model on epidemic or pandemic control outcomes, is lacking, conflicted, and contradictory.

This gap is more than an inconvenient deficit, however. It points to a troubling trend where practitioners in policy settings continue to communicate risk mitigation and health behaviour recommendations that have a limited basis in actual science. It demonstrates that there's a communication and knowledge exchange gap between the recommending policymakers and the scientists. Both areas need more robust findings in order for modelling exercises that would require parameterisation with these values to achieve desirable levels of quality.

There was no existing literature that directly addressed how the public perception of a particular scientific methodology might influence their confidence in the public health recommendations made on the basis of that method. In an age where science and health communication, scientific literacy, and public engagement are central to both inquiry and practice, it is highly advisable that all possible intersections of human perception, behaviour, and information dissemination that are pertinent to the development of policy recommendation are explored.

Further research directions in this area would include studies that explored individual reasoning for the effects we see in Chapter 3, such as contributing data to answer the question of why experimental methods and the opinions of experts are most likely to persuade people to behaviour change. Another recommendation would be to focus efforts on research in this area that is prescriptive rather than descriptive, in order to help guide both education and communication efforts in the future. While there is an existing literature that addresses communication effects and theories of health behaviour change, the role of the public's methodology perception in these areas is unclear. There is also room for more unification in the literature surrounding the construction of persuasive health communication that would be useful to policymakers and governmental organisations in designing successful health promotion campaigns and public-facing policy communications.

Data surrounding policymaking confidence in the outcomes of modelling exercises should be generated. The final design and implementation of a given public health or social policy could be profoundly affected by tension or confusion within a group using modelling to generate or evaluate evidence, and in-depth characterisation of this phenomena would be very useful for policy and public administration professionals who oversee and staff these committees, departments, and teams working on these issues. While the positive impact of interdisciplinarity on modelling team productivity and quality has been established here and in previous studies, what facets of interdisciplinarity, and indeed, which disciplines and skillsets, are most useful on these teams is poorly understood. Studies that could generate some evidence that would help guide the creation of teams that are most likely to be successful in modelling endeavours could be very useful to both researchers and administrators.

Finally, modelling methods are a prominent tool in sociotechnical systems, and there is an abundance of literature that employ them to answer a vast array of policy-relevant questions. Yet, few comprehensive efforts have been made, until now, to understand how these models are being used in policy practice, and how their use resonates outside of the peer-reviewed literature. Brief discussions about the perils of model parameterisation, model design, and understanding uncertainty exist, but too little attention has been paid to modelling in context, models as the primary tool by which policies are underpinned, and modelling as it exists in the public perception. These gaps are not a matter of intellectual curiosity, but of good public health practice. The confluence of the evidence presented in this thesis and the existing literature strongly suggest that modelling methods matter: how we use them, who uses them, where they are used, and how we are communicating their outcomes all play a role in whether the policies supported by them are successful, and the populations those polices address are healthy. Continued pursuit of robust knowledge in all of these domains is thus strongly recommended.

Appendices

From Chapter 3

Qualitative Analysis Coding Scheme

Qualitative Analysis Categories, Category Descriptions, and Examples of Respondent Quotes

Category name	Description	Illustrative examples from mini-interviews
Dimension 1 - WHAT MODELS *ARE*	**What models represent**	
Simplification	Models that represent a simplified or uncomplicated version of something	It's just representing the real world in something more manageable.
Unspecified representation	Models that represent something, without specification.	Something to represent something, like, an object to represent it...?
Theory	Models that represent abstract theory or structures (or *are* theory)	I think they mean … theoretical structures of … real life events.
Duplications of reality	Models that are duplications of the real world or copies of reality.	To me, it would be computer models, going through climate changes, or **full representation of the full global market** of what's going on.
Standard case	Models that represent the 'standard case'	**Like the standard model and** ... a template for something, like you would ... a way to explain something.
Idealised or perfect case	Models that represent an idealised or 'perfect' cases (to be aimed for)	Models? Erm … a perfect … example of something that you would want to aspire to, you know, with climates or anything I suppose.
Mock-ups	Models as mock-ups or prototypes (e.g. that represent something that will be built in the future)	I think they mean, like, they do a model before they do the real thing, first.
Non-Scientific / Vague	Answers that seem non-scientific or vague	(laughs) Erm, what kind of scientists? Erm, I have no idea … Probably talking about … health of people ... I don't know, I really don't know.
Dimension 2 – WHAT MODELS ARE *FOR*	**Uses of models and what they are used for by scientists**	
Simplification (Odenbaugh)	Models used to simplify complex phenomena in order to understand them better.	Yes, so something that you can make in either miniature or recreate in a science laboratory that can echo a real life event … yes. So you can make a model of a tornado by doing some clever … in a tunnel … you know, with controlled environmental pressure, and then that will be looking at what's happening in the real world with real atmosphere.
Exploration	Models used to look into the future to see how things might affect our lives in the future, extrapolation of current trends into the future.	Um, I take it they use it to look at things like strategies for the future or to identify areas that perhaps you need to have government intervention laws in place for things that could affect us in the future.

		(NB: Our definition is looser than that of Odenbaugh for whom this category referred specifically to the use of models to explore unknown possibilities in the form of 'what-if' questions or scenarios whereby the interest is in how models can be used to explore what might happen in conditions that do not match (current) reality.)
Generate new ideas	Models used to test scenarios that might arise (either naturally or as the result of regulatory control) and see how these would impact the world or society.	Um, I think it's ... they kind of put together scenarios ... that represent reality and then try and sort of **imagine how things might develop**. (NB: In Odenbaugh, this category refers to the use of models for the tightening up of ideas and concepts through making assumptions fully explicit through the modelling process, as well as the development of new concepts that are shown to be helpful in developing models.)
Prediction (Odenbaugh)	Models used to predict	Models? Erm, about, kind of making predictions, taking what we know already and trying to see if that trend will continue and the future. Models are ways of them trying to understand and analyse the environment, or world, for the purpose of making predictions about weather climate changes, and such. Alright, okay, um, models of course, they can help you to predict what might be going on in the future and what we should do at the moment to help us establish a sustainable living environment.
Explanation to Others (Odenbaugh)	This refers, in Odenbaugh, to the communicational role of models. In other words, this category does not relate to the value of models in trying to explain the mechanisms underpinning a phenomenon, but rather to the role of models in explaining those mechanisms and structures to others.	Again, something ... used to like, explain something, say, some kind of study, they used a model to explain the study. I would imagine a model of something that they use if you like to explain something.
Non-Scientific/Vague	Answers that seem non-scientific or vague	Em ... they put on the stuff that the one that they make, that they do, will have all of those things on it.

Questionnaire – From Chapter 3

1) Background information (please enter age and circle those that apply)

Age:	Highest level of involvement in science: School – High School – Undergraduate – Postgraduate – Professional research scientist
Gender: Male – Female	Attendance at public science events: More than twice in last year – 1-2 times over last year – Previously, but not for a while – Never

2) The questions below relate to methods used in science and how confident we can be about the findings. Take time to read each statement and tick the **one** box per line that best describes your view.

	Very high confidence (at least 9 out of 10)	**High** confidence (about 8 out of 10)	**Medium** confidence (about 5 out of 10)	**Low** confidence (about 2 out of 10)	**Very low** confidence (less than 1 out of 10)
In your opinion, what level of c*onfidence* can we have in scientific predictions or recommendations based primarily on the following sources of information, assuming that any research is carried out properly?					
Experience: The accumulated life experience of experts (e.g. doctors and nurses or climate experts)					
Experiments: Scientific experiments					
Mathematical models: Models that use mathematical equations					
Computer models: Computer models or simulations					
Historic studies: Studies using historic data					
Current data: Studies using recent data					
The questions below relate to levels of confidence required in science used by politicians to make policy.					
In general, how confident should scientists be about their predictions before the government uses them to make recommendations that affect their lifestyle to the public?					
Specifically in relation to flu, how confident should we be about scientific predictions that an outbreak will spread worldwide before making recommendations to the public that affect their lifestyle?					
Specifically in relation to climate change, how confident should we be about scientific predictions about climate change before making recommendations to the public that affect their lifestyle?					

3) How well do you agree with the following statements:

	Strongl	Agree	Neutral	Disagre	Strongl
Models are an important part of good science about infectious disease					
Models are an important part of good science about climate change					
The government should use predictive models when planning for flu pandemics.					
The government should use predictive models to plan for climate change.					

4) The questions below relate to the evidence for pandemic flu. Tick **all** boxes that apply.

	Experience of experts	Experiments	Mathematical models	Computer models	Historic Studies	Current data	No support
a) The findings below relate to *swine flu*. In your opinion, how are they supported?							
The predictions relating to the worldwide spread of swine flu							
How swine flu is passed from one person to another							
The link between individual behaviour and swine flu spread							
b) The recommendations below were provided by the government during the swine flu pandemic in 2009. How do you think they were supported?							
Washing hands with soap & hot water or using hand sanitizer gel often							
Using clean tissues to cover nose & mouth when coughing or sneezing							
Staying at home if you feel ill and think you might have swine flu							
Setting up a network of “flu friends” (e.g. to collect medicines)							
c) Considering the same recommendations, now respond to the following:							
I would believe that the recommendations would be effective in *protecting me* if these were based on:							
I would believe that the recommendations would be effective in *avoiding a worldwide pandemic* if these were based on:							
d) I would do the following things if I thought the evidence for these was based on … (categories above):							

Washing hands with soap & hot water or using hand sanitizer gel often							
Using clean tissues to cover nose & mouth when coughing or sneezing							
Staying at home if you feel ill and think you might have swine flu							
Setting up a network of "flu friends" (e.g. to collect medicines)							

5) The questions below relate to the evidence for climate change. Tick **all** boxes that apply.

	Experience of experts	Experiments	Mathematical models	Computer models	Historic Studies	Current data	No support
a) The findings below relate to *climate change.* In your opinion, how are they supported?							
Predictions relating to future world climate							
The relationship between greenhouse gases and climate change							
The link between individual energy consumption and climate change							
b) The recommendations below have been provided by the Government on ways to combat climate change. How do you think they are supported?							
Turning down your heating by one degree							
Buying energy saving products (home appliances or light bulbs)							
Choosing fuel-saving cars							
Driving less							
Flying less and offsetting carbon emissions							
Wasting less food							
Buying "climate friendly" foods							
c) Considering the same recommendations, now respond to the following:							
I would believe that the recommendations would be effective in reducing *my impact on climate change* if these were based on:							
I would believe the recommendations would be effective in reducing *society's impact on climate change* if they were based on:							

d) I would do the following things if I thought the evidence for them was based on … (categories above):							
Turning down my heating by one degree							
Buying energy saving products (home appliances or light bulbs)							
Choosing a fuel-saving car							
Driving less (only answer if you have access to a car)							
Flying less and offsetting carbon emissions							
Wasting less food							
Buying “climate friendly” foods							

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