Chapter 12
Conclusions

12.1 Model-Based Demography: The Story so Far

As we have seen from the examples presented in Part III thus far, the development of model-based demography is advancing, though still in a relatively early stage. Demography is a field with a lengthy and successful history, and by the nature of the research questions it poses, has always been linked very tightly with concepts of statistics and probability (Courgeau 2012). Far from preventing progress in the field, demography has been influential since its earliest beginnings, proving vital for the study of population change and the implementation of critical social policies relating to its core processes of fertility, mortality and migration.

Perhaps as a consequence of this, the introduction of a new methodology into a field with such an extensive history is one that bears careful consideration. After all, if statistical modelling of population data can still produce figures that journal editors, policy-makers, and research funders find useful and are happy to support, is there any particular need for new methods?

As outlined in Chap. 9, demography has wrestled with this question before, and in each instance has incorporated these new methods and used them to enhance its core strengths. Each of the four methodological paradigms we outlined – period, cohort, event-history and multilevel – developed in response to shortcomings in previous methods that left certain demographic questions out of reach. New methods that addressed these questions thus became part of the demographic toolbox, augmenting the field's capabilities but not replacing the methods that came before.

In that respect, model-based demography answers a similar call. The epistemological challenges posed by the problems of uncertainty, aggregation and complexity lend themselves toward a model-based approach. The application of simulation to demographic problems is not just in pursuit of novelty, but is a means to an end, offering the power to investigate and better understand the complex, multilevel interactions that drive population change. As with cohort, event-history, and multilevel approaches previously, model-based demography will become a key

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tool the demographic toolbox for certain categories of research questions, and the four previous paradigms will continue to be useful for other questions. Indeed, as we have seen in the examples in Chaps. 10 and 11, simulation models and statistical demography can work in combination to answer questions about complex social processes.

12.2 The Practice of Model-Based Demography

The modelling studies presented in Part III provide detailed examples of the application of simulation modelling methodologies in demographic research. We should note that the studies presented here are far from a comprehensive survey of the whole of model-based demography, though we have tried to present some of the key influences on these studies and acknowledge their critical contribution to the state of the field today. Without the efforts of Axtell et al., Billari et al., and numerous others, the development of model-based demography would not have proceeded so quickly and effectively (Axtell et al. 2002; Billari and Prskawetz 2003; Billari et al. 2007).

The Wedding Ring example in particular serves as a useful illustration of how simple models can add to demographic knowledge. Much like Schelling's residential segregation model (Schelling 1971), the Wedding Ring focuses on a single complex question and seeks to model a possible answer with very little in the way of data or complexity. In both cases, we are not able to offer specific point predictions about the future state of residential segregation or coming trends in partnership formation, but we are able to offer some new conclusions about the social functions underlying those phenomena. With Schelling's model, we can suggest that individual racial preferences may play an unexpectedly large role in the manifestation of residential segregation, and with the Wedding Ring we can propose that social pressure on the unmarried from the married can produce similar partnership formation patterns to those seen in the real world. Most fascinatingly, neither of these models required the incorporation of even a scrap of real-world data.

These modelling approaches thus hew closer to *systems sociology* as opposed to *social simulation* (Silverman and Bryden 2007, to appear). The outcomes of these models help us to understand the social functions underlying a population-level outcome seen in human society, but in neither case are we able to state anything specific regarding a real-world example. This is a marked difference from traditional demography, in which the overwhelming majority of research is applied in nature.

The Wedding Doughnut (Bijak et al. 2013; Silverman et al. 2013a) acknowledges this disconnect and attempts to resolve it, primarily through the integration of statistical demography. The model is extended to increase the influence of spatiality, and fertility and mortality, augmented by statistical demographic projections using real-world data, become key elements of the model's behaviour. The model remains a proof-of-concept more than a focused policy tool, but these extensions demonstrate

the capacity for simulation and traditional demography to work in tandem, and in the process harness the strengths – and mollify the weaknesses – of each approach.

The addition of uncertainty quantification in the form of Gaussian process emulators further eases the transition from statistical model to computational. The emulator provides key insight into the impact of simulation parameters, helping the modeller to redress the balance between precision and tractability. In practical terms, we can better understand the model's behaviour and provide more incisive analysis of the results. In pragmatic terms, modellers accustomed to formal mathematical models may feel more comfortable working with computational models that are less of a 'black box'.

12.3 Limitations of the Model-Based Approach

While the development of model-based demography provides new means for generating demographic knowledge, practitioners should remain mindful of the limitations of simulation as set out in Parts I and II. As with any modelling methodology, agent-based methods are best used to answer research questions that would explicitly benefit from modelling individual behaviours and interactions. When modelling problems that are closely related to complex social factors, agent-based models may provide a more suitable platform for explanatory aims.

12.3.1 Demographic Social Simulation

Revisiting the agent-based model of the Anasazi Axtell et al. (2002) provides an example. The model was built using archaeological data, and provides a useful platform for exploring how the Anasazi population eventually declined. However, as pointed out by Janssen et al. (2009), one could argue that the model did not result in a substantial change in the discourse around the Anasazi's decline. The authors' replication shows that, while the model results do closely mirror archaeological data and provide sensible conclusions, the model does not provide much information beyond a comparatively simple model based on the carrying capacity of the Long House Valley itself:

> Within model-based archaeology two approaches can be identified: (1) detailed data-driven simulation models that mimic observed trends like population numbers, (2) stylized models that are informed by empirical data but explore a broader domain of possible social-ecological systems. Which approach is the most appropriate depends on the research question at hand. The fact that the Long House Valley abandonment can not be explained by environmental factors is demonstrated by the original Artificial Anasazi, but it could also be explained by calculating the carrying capacity of the valley. A more comprehensive question like whether exchange networks increase the resilience of settlements in the US south west may need to be addressed by a series of models, including stylized models that simulate various possible landscapes. (Janssen 2009, para. 5.4)

In model-based archaeology, as in social sciences more broadly, the data-driven *social simulation* approach and the abstract, theory-driven *systems sociology* approaches are in evidence. In the case of the Anasazi simulation, one might argue that the model may have been more powerful than was actually demanded by the research question. We might propose as well that the model in this case served a useful role by confirming a result through a more detailed modelling approach, as well as providing a useful example of model-based demography in practice.

The choice of whether to apply an agent-based model to a particular question is not always going to be straightforward, and there is often the chance that a model may be overkill for certain types of research questions. However, as in the case of the Long House Valley model, the model can serve additional purposes beyond testing a hypothesis, by providing a test case for a particular approach, generating new questions that can be examined with a refinement of the model, or by directing future data collection.

12.3.2 Demographic Systems Sociology

The Wedding Ring and Wedding Doughnut provide a useful example of the more abstract side of agent-based demography. These models are more generalised and abstract in their approach, in contrast to the Anasazi model. The Wedding Ring eschews empirical data entirely, building a model focused on testing a particular theory about the influence of social pressure on partnership formation timing (Billari et al. 2007). The approach is more in line with a systems sociology approach, in which we are examining the impact of social factors on a population-level phenomena without reliance on empirical data. The theoretical focus of the model is acknowledged from the outset, and as a consequence the model provides both a useful exploration of theory and an influential proof-of-concept for demographic models with similar research aims.

The Wedding Doughnut (Bijak et al. 2013; Silverman et al. 2013a) takes the foundations of the Wedding Ring and takes them in a more empirical direction. Empirical data is used to generate the initial population and to drive the patterns of mortality and fertility amongst the agents. A simple model of health status is added to illustrate how simple models can still be relevant for the study of social policy. The model does not fully make the leap into social simulation, however, as the authors are not aiming for specific point predictions regarding social care need or UK population change; instead, the model provides an example of the integration of statistical demography and agent-based approaches.

In an empirically-driven discipline like demography, models like these stand out as a more theoretically-driven approach. This can easily lead to misunderstandings, as the results may seem to lack relevance to real-world population change, and too ill-informed by population data to provide demographic insight. However, as noted by Courgeau and Franck (2007), a demography which exists to operate only on successive sets of data using identical methods is not a field which is progressing

as a scientific practice. Model-based demography can provide a means to expand the theoretical innovation of demography, as illustrated by the Wedding Ring and subsequent extensions.

In practice, the makers of such models should be mindful of their theoretical backstories, and ensure that the assumptions underlying their construction are clearly delineated from the start. Setting out the aims and purpose of a more abstract model will ensure that the results are properly placed into context by readers, and alleviate potential misunderstandings due to misapprehension of the model's scope and intended impact. This will also help to ensure that comparisons between models and demographic approaches will be made on a *like-for-like* basis. Demographic systems sociology models will not evaluate well when compared against statistical models of a particular population, for example, given that the simulation in that case is not aiming for theoretical relevance in the first place – but if the intended scope of the model is not laid out from the outset, that may not be clear and could lead to a negative evaluation of the methodology by the community.

12.4 The Future of Model-Based Demography

Model-based demography clearly has potential as an approach to certain types of demographic problems, both focused empirical questions and broader, theoretical concerns. However, the unique characteristics of agent-based approaches in particular suggest some particular avenues where this approach would be most fruitful.

The demographic extension of the Linked Lives model discussed in Chap. 11 (Noble et al. 2012; Silverman et al. 2013b) demonstrates the potential of agent-based demographic models for the study of major social policy concerns. Demography has a long history of empirical relevance, and is frequently used by policy-makers to guide their decisions (Xie 2000). The Linked Lives model aims to leverage this strength by combining statistical demographic elements with a detailed model of the supply and demand of social care in an ageing UK society, a problem receiving a great deal of focus in the UK political context at present.

The simulation is built around a simplified version of UK geography, in which individual agents live, form partnerships, migrate, and provide care for loved ones. The original Linked Lives model (Noble et al. 2012) focused on the implementation and demonstration of the model as a useful platform for the examination of the cost of social care; the subsequent demographic extension (Silverman et al. 2013b) incorporated UK census data and demographic projections of mortality and fertility to enhance the realism of the model. This combination produces population dynamics that accurately reflect demographic projections of the UK population.

More importantly, however, the extended model demonstrates how a model of this type can provide unique insights into policy-relevant problems that benefit both from demographic expertise and the modelling of complex interactions facilitated by an agent-based approach. For example, the model illustrates that a policy change that might at first blush seem largely irrelevant to the cost of social care – in

this case, increasing the retirement age – has a significant impact. The presence of retired carers actually accounts for a surprisingly large amount of the informal social care being provided in the model, and as a consequence, keeping older potential carers in work longer can backfire when the retirement age is raised too high (Silverman et al. 2013b). This result anticipates the later analysis by Age UK, which highlights the significant cost savings to society provided by these selfless older citizens (Age UK 2016). The use of Gaussian process emulators to confirm the impact of the retirement age parameter further increases our confidence in this result, allowing us to peer deeper into the workings of the model and determine key parameters that may be of particular importance to policy-makers concerned with social care.

While the model remains more of a proof-of-concept, and does not claim to provide specific and solid predictions for the future of UK social care, it does provide a useful exemplar for future excursions into policy-relevant model-based demography. Despite the relative lack of data compared to data-rich microsimulations, the model is able to provide significant insight into the dynamics of social care supply and demand. The incorporation of UK demographic data shows that simulations can be linked closely with population data in a relatively straightforward way. Finally, the use of uncertainty quantification in the form of emulators allows us to more thoroughly explore the simulation's parameter space, and in the process generate scenarios that help us examine possible futures under a wide variety of possible policy shifts.

Thus we may imagine a future for model-based demography in which the approach becomes a trusted tool for the study of empirical questions of population change where social factors are of particular relevance, but also where it flourishes particularly when applied to systems sociological models driven by social theory, and policy-relevant models aimed at the generation and exploration of scenarios. The latter case offers another area of growth for demography, where the implementation of models combining population data and complex agent behaviour allows us to create 'policy sandboxes' where future population trends can be studied under a variety of possible futures. Interacting with models of this type can help policy-makers to spot potential spillover effects of policy changes before real-world implementation, and assist them in the creation of evidence-based policy informed by real-world population data and a scientific approach to the modelling of populations.

12.5 Model-Based Demography as an Exemplar for Social Science Modelling

In Parts I and II, we examined the methodological difficulties inherent in the use of agent-based modelling for the social sciences. By bringing together methodological analyses from Alife, social simulation, population biology, and political science,

we established the importance of a theoretical backstory for any given modelling enterprise. These backstories delineate the assumptions on which our models operate, the intended scope of the model, and the level of artificiality we ascribe to the model and its results.

In practice, however, addressing these concerns in detail every time we develop a model seems redundant at best, even a waste of time at worst. The practice of modelling often requires an iterative approach, in which previous simulations are extended in various ways, tested and at times discarded, and as a consequence each instance of the model could approach each of these elements slightly differently, even if the overall research aims stay largely identical.

12.5.1 The Advantages of Developing a Framework

In the case of model-based demography, we are able to alleviate this additional explanatory burden somewhat by developing a widely applicable methodological framework – a paradigm which seeks to justify the general practice of modelling population change in this way from the outset. Under this methodological paradigm, modelling is focused on a classical scientific approach, informed by data and tasked with studying the social factors underlying the processes generating population change. As model-based demographers we seek the integration of demography's greatest strengths – rich population data and a centuries-long history of statistical expertise and innovation – with simulation's ability to surpass some troublesome epistemological limits of demographic knowledge (Courgeau et al. 2017). By extending the concept of the *statistical individual* to the *simulated individual*, we establish model-based demography as a descendant of the methodological tradition of the discipline, and enable a generation of researchers to embrace a new technique without overly troubling themselves with the finer points of Artificial[1] and Artificial[2].

The advantage of this kind of approach is significant. Establishing the theoretical backstory in advance as a methodological addition to the field, or as a sub-field, allows us to approach each new model identifying as 'model-based demography' with a pre-existing knowledge of the likely scope and intent of that model. Where models depart from the core concepts of model-based demography, this can be established when documenting the model by making reference to this paradigm. We are able to spend more time constructing and validating models, confident that our intentions will be understood by the community at large without excessive explanation.

Additional complexities do come into play, however, when we reach the stage of analysing the results of our complex demographic models. If the advantages of model-based demography are to be truly realised, then methods which enable us to understand the impact of model parameters on population-level phenomena should continue to be refined. Uncertainty quantification methods like Gaussian process emulators provide a useful starting point here, and if model-based demographers

begin to embrace these techniques then it is likely we will see continued refinements in the future as we begin to adapt them to the particular case of agent-based social simulations.

However, the development of a backstory remains important when working with demographic systems sociological models. Abstract models are simpler in their construction, generally speaking, but are not necessarily simpler in their implications, as we saw with Schelling's residential segregation model (Schelling 1971, 1978). Establishing the scope and artificiality of a model is significant, as simplistic models can easily be misconstrued as making overly ambitious claims otherwise.

12.5.2 Model-Based Social Sciences

The example of model-based demography illustrates the advantages of developing a methodological paradigm as a kind of collective theoretical backstory for an approach to simulation with a specific discipline. The specific case of demography somewhat lends itself to this way of doing things, however; demography boasts a lengthy history and a notable ability to absorb and refine a wide variety of statistical approaches. In that context, establishing another methodological framework to underwrite the use of simulation seems an appropriate way to situate simulation as a tool worthy of the same respect as statistical modelling.

In other areas of social science, however, the range of methodologies in use can be much wider. We see researchers gathering data qualitatively via interviews or surveys, or others analysing texts or artwork, or studying the geographical distribution of people, artefacts and customs. Many of these disparate methods can provide useful knowledge that can be utilised in simulation (Gilbert and Troitzsch 2005), but this does not mean in turn that the simulations will be considered trustworthy or appropriate tools to those same researchers.

In this context we cannot simply write variations of the model-based demography framework as *model-based social science* and expect them to provide an appropriate theoretical backstory for such a broad range of research questions and methods. However, model-based demography does demonstrate a process which can be more transferrable. Model-based demography as a framework addresses core questions that are just as salient elsewhere:

1. What are the key questions asked by our discipline?
2. What is the main unit of analysis in our discipline?
3. What are the main epistemological limits within our discipline?
4. Which of these limits can be addressed in some way using simulation?
5. How can our analyses inform a simulation process?

Model-based demography suggests that simulation efforts in other areas of social science would benefit from a concerted effort to address these core questions, and in the process situate the approach clearly within a disciplinary context. Doing so

not only alleviates some of the difficulties outlined above, but it provides a common backstory which also clarifies and communicates the aims of the work to others *outside* the discipline. This in turn allows for easier collaboration between social scientists and simulation practitioners, and eases the time-consuming process of developing a common language in simulation collaborations, which can inhibit progress significantly in new simulation ventures. Collaboration across disciplines also becomes easier, as each member of the collaboration would have a clear statement in hand of the methodological aims and limitations of the work to come.

In a sense, perhaps, we would benefit from developing *modelling manifestos* of sorts. Rather than individual justifications of each model, establishing a united front through which we can embark on journeys into simulation allows us to get on with development and implementation using a common framework. Some models, particularly those of a more abstract, systems-sociological bent, will need to pay more attention to individual statements of scope and purpose, but given the more theory-driven and explanatory nature of such models this is naturally part of such an enterprise anyway. Developing such 'manifestos' will certainly spawn its own protracted arguments and divisions, naturally – we are academics, after all. That being said, with the splintering of so many disciplines into sub-disciplines and sub-sub-disciplines, we might benefit from occasional forays into self-reflection on the goals and limitations of our work and how it relates to our colleagues elsewhere in our own disciplines and neighbouring ones as well.

12.6 A Manifesto for Social Science Modelling?

By most measures this volume makes for a rather unwieldy manifesto for social modelling – the word count is excessive; it covers far too many disciplines; and many of the conclusions are highly malleable depending on the reader's own disciplinary background and research convictions. Fortunately, this volume is not intended to fill that role; specialists within the varied specialisms of social science are far better equipped to handle the task of establishing approaches to modelling in their particular context (see, e.g., Conte et al. 2012).

This volume set out to expose and discuss the challenges faced by simulation modellers, starting from the earliest pioneers in simulation (Schelling, Langton, and the rest) and moving toward the current growing interest in models of human sociality in many different flavours. By bringing together insights drawn from Alife, population biology, social simulation, and demography, we are able to develop a better understanding of the power and the limits of simulation when applied to the social sciences. The development of model-based demography shows us how simulation can be investigated, applied, and refined for a particular social science context.

Ultimately, the further advancement of social modelling will still require significant work, both theoretical and practical. Conversations will need to be started between colleagues who hardly understand one another; conceptual chasms will

need to be bridged; and social scientists will need to work with programmers and computer scientists who may have very different views of the world. Hopefully the discussions brought forth in this volume might make those discussions somewhat easier, the bridges a bit shorter and easier to construct, and the gaps in practical and disciplinary knowledge between social scientists and computer scientists less insurmountable. If it facilitates some heated debates over the writing of some modelling manifestos, then so much the better.

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