How Should Agent-Based Modelling Engage With Historical Processes?

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Abstract. This paper consists of two main parts. After an introduction, the first part briefly considers the way that historical processes have been represented in ABM to date. This makes it possible to draw more general conclusions about the limitations of ABM in dealing with distinctively historical (as opposed to merely dynamic) processes. The second part of the paper presents a very simple ABM in which three such distinctively historical processes are analysed. These are the possible significance of unique individuals - so called Great Men, the invention and spread of social innovations from specific points in time and the creation of persistent social structures (also from specific points in time). The object of the paper is to advance the potential applicability of ABM to historical events as understood by historians (rather than anthropologists or practitioners of ABM.)

1 Introduction

> "The assumptions you don't realise you are making are the ones that will do you in." (Trad. Anon.)

Like all disciplines, ABM has its particular perspectives and implicit assumptions. These may remain undiscovered while it keeps "safely" to certain known areas of research but may show up very clearly when it attempts to broaden its application. This paper is a case study of that situation with respect to the study of history.[1] It arose from discussions with historians in the context of the evolution of networks in the book trade but set us thinking about wider issues connected with distinctively historical explanation. The paper has a very simple structure. After this introduction, which very briefly considers what we might mean by historical analysis, the first part carries out a literature review of ABM applied to historical topics or published in historical outlets. It uses this as a sample (small but nearly complete) to induce general claims about the present "historical" uses of ABM. These general claims can then be examined and challenged. The second part of the paper addresses these challenges and uses a simple ABM to show several phenomena that can be seen as

[1] Such challenges can be productive if they force ABM to reconsider its implicit assumptions and broaden its scope. Conversely, a dogmatic reaction to such challenges is likely to harm the likelihood of ABM being accepted more widely.

distinctively historical but have not been found in historical ABM to date. As shown in the conclusion, this ABM is thus a jumping off point for a possible dialogue between history and ABM about "historical models" that may have mutual benefits.[2]

Before analysing existing historical models in ABM and suggesting ways to make them "more historical" it is necessary to say something about what history might be. Understandably huge amounts of ink has been spilt on this topic by historians and others so it is very important to avoid issues that ABM researchers will probably never be qualified to comment on (like "how should history be done?") Nonetheless, it is relatively straightforward to identify some assumptions without which it is hard to see how a process could be defined as "historical". The first is a changing population of agents. This is meat and drink to ABM but many social science studies effectively work with fixed populations. Certainly over several centuries, the kind of time scale we think of as most "typically" historical, the entire population will inevitably have changed. The second assumption, related to the first, is that history is the sort of time scale over which *ceteris paribus* assumptions do *not* apply. We can see this by contrasting history with the sort of cross sectional statistical analysis often carried out in sociology (for example). We might find a particular association between class origins and educational success in 1980. It might not be unreasonable to say, comparing that with the relationship found in 1975, that the institutional framework (for example the structure of the school system) was "more or less" unchanged and therefore that changes in the parameters of the model reflect changes in society (more equality of opportunity in the educational system for example). However, it is very clear that such a comparison with *1780* would be more or less meaningless because the education system would be so radically different (as would the logic of the entire class structure). History is thus the time period over which it is *not* reasonable to take social practices and institutions (or other social structures) as a fixed background to the wider social process. In fact, looking at existing non-historical research, it is not really clear how long that period might be and it is therefore important that ABM can cope with "historical time" if required. Clearly things do not remain constant over centuries but actually, for example, there was pretty radical change in the UK education system under Margaret Thatcher and while statisticians may choose to *treat* five years or so as a non historical period, whether that assumption is unreasonable (and more importantly whether their methods can *reveal* it to be unreasonable) is another matter. The final assumption that is worth noting (although it will not be relevant until *empirical* historical ABM are developed) is that the supply of data for historical analysis is fixed (even if some of it still remains to be discovered). Unlike much social science where, if data is missing it can be collected, the historical record is now fixed. These brief considerations set the scene for a consideration of existing "historical" ABM and how "more" historical variants of ABM might be developed.

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[2] Traditionally, history has been quite wary of "theory", let alone "models". Arguably history faces, to an even greater degree, the sort of challenges that have made social scientists wary of modelling based on statistics and equations. Some of these concerns will become clearer in the course of this paper.

2 ABM and "History": A Very Brief Analytical Review

Although examples of equation based theorising can be found on historical topics [1, 6, 17], these are relatively rare and will not be discussed further here. ABM approaches to history are a little more common (despite the shorter effective lifetime of these techniques) but their increased frequency seems to reflect a broader conception of history rather than a greater interest in the approach.[3] In particular, it seems that most apparently historical ABM actually involve what we might call an anthropological conception of history [2] in which agents behave according to fixed social rules that are simply played out over time. The clearest examples of these are research that is explicitly anthropological or archaeological [14, 16, 21, 23, 24]. However, other examples of ABM with this anthropological conception of history are those that (while dealing with clearly historical events) do so over sufficiently short time periods that behaviours and structures are also assumed to be constant [4, 15]. Formal theories involving genuine structuration (agents create structure which then acts on them) appear to be absent.[4]

Two apparent counter-examples to this claim prove not to be on closer examination. The first are what we might call possible worlds ABM. In this case, the ABM can be used to examine counterfactual cases ("suppose the flu had struck at a different time of year" – see [15] for example).[5] This might give an impression of changing rules but the impression is mistaken because in each simulation run these are fixed and the results are compared across runs (a process that has no real historical equivalent).[6] What is not happening in these ABM is what appears to happen in history, namely that individual actions give rise to structures (for example institutions like "The Metropolitan Police") that subsequently have effects of their own. The other

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[3] We will also exclude from this discussion research advocating ABM but based only on the work of others, for example [7, 9]. Instead we will discuss these examples directly. However, we will not discuss separately multiple publications on the same project. Also, for practical reasons, and without prejudice to its quality, we shall not discuss non peer reviewed work including research by Kerstin Kowarik and colleagues on prehistoric salt mining, Jim Doran on insurgency and Giuseppe Trautteur and Raniero Virgilio on the Battle of Trafalgar. More information on this work and actual copies of draft papers may be found on the web but these sources are not academically robust. The authors would be glad to hear of any work (unpublished or not) that contradicts our hypotheses here so we can refine our analysis.

[4] The emphasis of this paper is on publications by historians and/or those in historical outlets. However, the same appears to be broadly true of "historical" research (generously conceived) in ABM journals. For example, none of the models in Mithen's excellent chapter [20] appear to involve social innovation. [8] is a rare debatable counter example to our general claim in that, although cognitive complexity can increase (allowing for the evolution of hierarchy for example) the environment appears to remain fixed.

[5] The status of counterfactuals in history is strongly contested to the point where it cannot plausibly be resolved here. Although there has been a lot of research based on this idea [12], it the approach has also been vigorously criticized not just in its details but also as a legitimately rigorous approach [10, 26].

[6] Again, we wish to avoid judgements about what history is. If one were asking "What caused WWI?" then the events that actually occurred would be all we could analyse. If, on the other hand, one were asking "What causes wars?" then one could construct a sample for study comparing different circumstances when war did and didn't occur.

set of examples are referred to as "history-friendly" ABM [13]. In fact, this doesn't mean friendly to historical analysis but making use of stylised facts about history in designing ABM that are still arguably a-historical. While it is true that firms arrive and depart from markets and new drugs are created in a stylised form (for example), there is no sign of changes in regulatory or market structure. As before, in practice, the same rules are in operation at the end of the simulation run as at the beginning even though, at different times, they may give rise to more or less numerous firms or more or less novel drugs.[7]

The most sophisticated case of a historical ABM we have been able to find is [11]. In investigating starvation, this represents both citizens and councillors as interacting agents to explore the effect of policy on hunger. However this article still involves an anthropological conception of history in that the rules of citizens and council seem to be fixed over the simulation run and merely played out over time. Even though this ABM does involve an explicit representation of a separate policy agency, it still doesn't allow for things like citizens banding together and overthrowing the council or the council reflecting on its past failings and innovating radically in its policy-making.

These examples suggest that ABM appears to have blind spots about what makes history distinctive. Institutions and social practices both change over historical time. It is for this reason that the case study in the next section explicitly attempts to represent genuine social innovation and the development of institutions albeit in a stylised form.

3 A Case Study of "Historical" Network Dynamics

In this section we present a case study of an ABM representing the evolution of social networks and some variants of potential historical relevance. Before doing this, however, it may be helpful to provide a brief introduction to the idea of social networks.

Social networks are structures formally defined by two elements: Nodes and relations. The generality of the approach arises because both nodes and relations (often called ties) can be many different kinds of things. For example, nodes could be countries and relations the volume of trade that flows between them each year, nodes could be pupils in a class and relations could be how much they like to work (or play) together or nodes could be elements of the book trade (publishers, authors, dealers and customers) and the relations could be the buying and selling of books. The

[7] Another arguable case would be adaptive systems based on evolutionary algorithms [5]. On one hand, a firm might start with a "practice" (represented as a genetic programming tree perhaps) that involved calculating a price based on cost and "end up" simply following the price of a dominant firm (a very different kind of practice). On the other, the genetic programming grammar and so-called "terminals" of the system (the variables on which firms calculate: for example own unit cost or price charged by another firm) remain fixed throughout a simulation run. It would seem to be an open question whether the "potential" novelty enshrined in a formal grammar is adequate to capture the novelty found in the real world. I would guess not.

interest in this approach is the associations that can be found between network structure and other phenomena of social scientific interest, for example that less well-connected pupils in a classroom might also be the weakest academically.[8] Thus social networks enable us to understand how one conception of social structure (who is connected to who by various relations) may affect social processes and outcomes. To take a book-dealing example (the area of history that inspired this paper), we can imagine a situation where every British county has always had (or at least ever since there was any market for books at all) a few people who were willing (and able) to buy books even if they have to come from a very distant city. These people can then have a network influence on others in the neighbourhood who they know or know them (perhaps by lending books, by a desire for social emulation or through education) to create a demand for books. This demand (though obviously coupled with non network factors like the general growth of literacy, the expansion of transport systems and so on) can reach the point where a local town can now support its own book dealer. This not only draws in more local customers who could not afford or would not countenance ordering books from London (thus increasing local demand further) but may also change the nature of the institutional distribution network. (Instead of London dealers selling direct to provincial customers, publishers may now start to deal directly with a growing circuit of provincial bookshops. This in turn may facilitate the sustainability of bookshops in other towns along their dealing routes.)

To gain a better understanding of what might be needed for a "more historical", ABM let us consider an evolving network where the nodes and relations are not supposed to represent any particular thing (though there are a number of historically interesting things – like book dealing networks – which they *might* represent). All we assume about the application of the ABM at this stage is that these nodes represent individuals (rather than organisations or nations) and that they have reasons to change over time.

Because ABM and the social process specifications that underlie them are intrinsically dynamic, we immediately face an interesting example of what history almost certainly isn't. Whatever processes we believe underlie the dynamics of social networks, it seems unlikely that history means nothing more than any event unfolding over time. Under that definition the network that forms between college students living in the same accommodation block over a month would be no more or less historical than the banking networks that grew up across Europe over centuries. Nor does it help to declare arbitrarily that things happening over months aren't historical while things happening over centuries are. Presumably what makes something historical is the kind of things that happen during the period of analysis (as suggested in the introduction). It is establishing what these kinds of things might be that underpins the argument of this paper about a profitable debate between historians and ABM researchers.

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[8] This can be contrasted with a "statistical" view often found in sociology that individual attributes are caused by (or at least associated with) other individual attributes. According to this view we should look for differences in educational attainment in terms of gender, ethnicity, class origin and so on rather than network position.

To take an example, if nothing else, something that is certain to change over historical periods is the population. People will be born and die. History is obliged to deal with these demographic phenomena in a way that short term sociological studies often are not. Interestingly, existing (mathematical) SNA struggles with networks where the population of nodes changes and, perhaps surprisingly, often solves this problem by just eliminating such cases from analysis (see [25], p. 138). By contrast, the approach used in ABM is much more intuitive for this aspect of history. New agents appear in the world at birth (and can then form network ties) while existing agents die and disappear (and their network ties vanish.)

The baseline ABM for this case study is one in which (starting with an initial population of 500 agents) one new agent has a 0.3 chance to be born and a randomly chosen existing agent has a 0.3 chance to die in each time period. (This means that the population of agents who can form ties is constantly changing but on average the population remains reasonably stable. New agents start with no ties and when an agent dies all its ties are broken.) Each agent is assumed to have a fixed maximum capacity for close social relations (which can vary between 1 and 6).[9] In each time period one agent is selected at random and (with a small probability for each potential tie they have not yet made) tries to make that tie at random with another agent that also has capacity. If no such agent exists then these friendship attempts fail, at least in the current time period. (Because agents have capacity for few ties and the probability for making each potential tie is small, the upshot of this is that mostly, the chosen agent makes no new friendship tie in a time period, sometimes just one but almost never more than one. This reflects the fact that close friendships form rarely but are long lasting.)

As already suggested, the lack of realism in these assumptions hardly needs remarking. Nonetheless, even this arbitrary ABM does capture some key points about social networks. Firstly, most people have very few close ties. Secondly, there are reasons why networks change regardless of personal inclination (in this case just birth and death but in more complex ABM also migration, differential contact opportunities and so on.[10])

In fact, this baseline model is just a version of the Giant Component[11] model found in the NetLogo models library but without immortal agents.[12] Since the "result" of the

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[9] This assumption is empirically supported [19] and probably reflects the effort involved in maintaining close relations as well as the increasing pleasure to be derived from them. People can have millions of Facebook "friends" at the click of a mouse but usually have only a handful of really close non-family relationships that may have taken years to build.

[10] Even this very simple ABM also allows for more subtle social process effects. For example, someone may want very much to make friends but be unable do so at one point in time. However, at another point, they may be in a position to make several friends rapidly. This mirrors the fact that although our number of friends may remain fairly constant, their actual identities often change when we undergo a major life event (like starting university or becoming a parent.) This phenomenon of "friendship churn" is empirically important but barely visible in formal SNA as far as we have discovered.

[11] The largest component in a network is called the Giant Component (hereafter GC).

[12] The simulations here were written in NetLogo [27]. The Giant Component Model code was also developed by Uri Wilensky [28] and has been further extended for research purposes with his permission.

standard GC model is the perhaps slightly counter-intuitive formation (fairly rapidly) of the GC, it is perhaps not surprising that what the "demographic" variant of this model produces is relatively stable component size distributions even though specific components are created and destroyed by the birth and death of crucial[13] agents.[14]

In fact, this is just what we find. In our baseline ABM, the long-term behaviour that emerges from the system is a reasonably stable set of components (one fairly large and the others much smaller). We averaged the size of the giant component (expressed as a fraction of the population to control for demographic effects) for 4000 time periods (because the giant component size is quite noisy owing to births and deaths). This was done at two different points in the simulation run (time periods 12000-16000 and 20000-24000) for reasons that will be explained shortly. This exercise was repeated for ten different simulation runs so variation between runs could be assessed. The result was that there was no significant difference between the average giant component sizes for each measurement period (0.65523 versus 0.65502). The small difference that was observed was dwarfed by the variation in giant component sizes in different simulation runs (which was nonetheless quite small) suggesting that the simulation had reached a steady state with respect to the changing population when the measurements were taken. This case thus serves as a robust baseline for variants to the ABM presented shortly.

This process draws attention to another interesting advantage of ABM from the perspective of history. This is the ability to repeat simulation runs differing only in the instances of random numbers involved. This allows us to think about counterfactuals. What can we make of statements like "Had Hitler not risen to power, the disastrous state of Germany would have made it almost inevitable that some other demagogue would have done so." In repeated runs of a simulation we can say, for example, that although persistent completely connected networks are observed (in 2 out of 1000 runs), it is very much more likely that two or three stable components will be observed (in 990 out of 1000 runs.[15]) Obviously, history is always what we have actually found happening but we cannot know how unlikely the observed case was relative to other conceivable outcomes. ABM at least allows us to talk about that state of affairs in a meaningful manner.

In the previous section, we sharpened the discussion about the role of ABM by suggesting why we might not consider just any dynamic process historical. Most historical theories seem to involve a situation where social practices and/or social structure change over the course of the analysis. We have already considered what happens when that change just involves the population (which already rules out a surprising amount of sociology and traditional SNA for example). This provides our

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[13] In this instance an agent is crucial if, by dying, it breaks a component into two smaller ones. An agent needs not be crucial if there are multiple routes between other agents in the component (because components are defined just in terms of connectivity and not distance.)

[14] To use another example from book trading, dealers would bequeath their stock on death (and it might then be sold by legatees) so bookshops might persist with different owners/operators.

[15] And in all simulation runs for each variant ABM, we found no qualitative variations in behavior (there was never an occasion when the GC size remained higher after the death of a unique individual for example) allowing us to be provisionally confident in the outcomes reported.

baseline ABM. In the rest of this section, we consider three other things of potential historical relevance that might change.

The first, which is a slightly odd example (in that it is almost a part of the history of history), is a stylised attempt to incorporate Great Men (obviously, in fact, Great Persons but hereafter GM) into the ABM. The GM debate (between the views of Carlyle and Spencer) may seem on the face of it dated and perhaps even pointless [3]. Because of the problem with counterfactuals, can we really say meaningfully that without Napoleon or Emmaline Pankhurst a particular outcome (World War I, votes for women) would never have occurred?[16] Perhaps not, but we may nonetheless be able to make better sense of this debate using an ABM. In fact, of course (like all important debates), this one echoes very deep matters, in particular the role of individual agency as against "social forces" or the net effects of many individuals doing what they do habitually or without reflection. Given the ships, the institutions and the sailors, could anyone have won Trafalgar or did it take someone with the arguably unique calibre of Nelson? (Assuming that his calibre is not simply deduced from winning Trafalgar!) Are leaders simply figureheads for events which (for much larger reasons) would almost certainly have occurred at around that time anyway? (Hopefully nobody is going to appoint a complete idiot to be in charge of a fleet during a period of major naval engagements but maybe all victory took was actually any one of a number of recognisably competent admirals.) In a historical context it is quite hard even to make sense of such questions let alone answer them. In an ABM, by contrast, it is much easier. Recall that, so far, we have assumed that all agents have a fairly small maximum capacity for forming ties (1-6). Suppose at a particular moment in time we create an agent with a much larger tie capacity (100-1000). For the purposes of this argument, the ABM is simplified in that this is the *only* way in which the GM differs from other agents. "He" has the same potential life span, is not treated any differently by others and makes his ties by exactly the same decision process. (Although because he has much more tie capacity, he actually forms many more ties in a single time period on average.) Following the same measurement process as before, we compare the average size of the GC for 4000 time periods before the birth of the GM and 4000 time periods after his death. Again, we find no significant difference between the average giant component size in the two periods with the whole simulation being run ten 10 times (0.64518 and 0.64769). What we observe (with images of the simulation runs available on request from the authors for reasons of space and to avoid colour reproduction) is that the GC increases dramatically in size during the lifetime of the GM but then immediately reverts to its previous size on his death. In retrospect, it is easy to understand what has happened here. By making many friends at once in several time periods, the GM immediately makes himself very central to the network and at the same time makes it very vulnerable to his death. Although all the other agents continue to make ties randomly, these are not directed at sustaining the large component created by the central GM so his death always causes it to fragment.

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[16] And if not "never", then how long does it take before the event is no longer "the same?" Could the rise of dictator in Germany in 1990 still be "counted" as the inevitable working out of an alternate history where Hitler did *not* come to power?

Now in a sense this is not obviously interesting from a historical perspective. I doubt anyone would claim that the world is no different with kings than without them or that people of exceptional abilities have no impact even when they are exercising them. But what is much more interesting is what this stylised ABM reveals about the nature of the GM debate. It appears that it is not enough for there just to be a GM, he also has to leave something tangible behind.[17] What makes the GM great, as far as history goes, is not just that he won the battle but that the battle resulted in a treaty that changed who owned which colonies subsequently (in other words some institutional or wider behavioural change). Historical studies are thus (as we have already suggested) most likely to find a use for ABM that can cope with this situation of ongoing structuration (rather than those which simply unfold the implications of fixed rules over time).

Thus, even though a GM in the sense presented here is neither historical nor plausible, this very stylised ABM still allows us to see clearly what we might mean by changing the course of history. In the context of a theory of evolving networks we can ask whether (and how) a GM could produce a lasting change in network structure such that the world is truly different thereafter than if they had never lived.

Further, thinking about the problem in this way enables us to dig more deeply into the rather nebulous idea of individual agency versus "social forces" that seems to underpin the GM debate. By assumption, in the ABM, all agents make their network formation decisions in the same way. The GM is only different in being able to form many more ties than the ordinary agent. We might expect, therefore, that the GM *couldn't* have a lasting effect. Social forces in this context mean the great mass of people with small tie capacities being born, choosing their ties at random and then dying. But, of course, these ties are not strictly random. They depend on both chooser and chosen having capacity and this in turn depends on births and deaths. If the GM has the capacity to change the overall structure of the system (for example by creating a very centralised GC) then this may change the choices open to new agents in perpetuity or at least for very long periods. The question then becomes what effect (or effects) does the GM need to have for this to occur? In the ABM discussed here, clearly forming lots of random ties on your own account is not enough. But we have started to move the GM debate from a contest between abstract philosophical positions to an exploration of different ABM assumptions that might, at least in principle, take account of data.

But this insight takes us further in our thinking in an important way. What would be impressive about this situation from a historical point of view is that even though the greatness of the GM was only manifested in his lifetime (and left behind no tradition of changed behaviour like Jesus or formal institution like the UK Civil Service after Trevelyan) it is still possible for an imprint of that greatness to be left behind (in this case in the equilibrium structure of dynamic social networks.) This makes what we mean by changing the course of history better defined and also more

[17] In this case, the GM sometimes visibly disrupts the robustness of the network afterwards although it gradually recovers to the previous level by "social forces" (the habitual actions of the mass). We could tentatively link this to the succession problem in politics [22]. A crucial role in a network is not beneficial for society unless you can pass it on to someone adequately competent. This issue motivates the third "institutional" variant of the ABM presented here.

interesting in certain ways. In a sense, after reflection on this case, it would be much less surprising if someone did this by leaving behind Krupp or the Catholic Church as stable bureaucratic entities that can perpetuate themselves. However, the idea that someone can, through activities only in their own lifetime and leaving no trace in the behaviour of others, leave their mark on a system that is constantly changing through individual demography and decision is a historically intriguing one, unlikely to be identified or articulated clearly without ABM (even using a ridiculously stylised example).

This discussion leads to a second variant of the ABM in which, after a certain point (time period 16000), one agent starts to make their network ties by an innovative decision process (choosing the least connected agent rather than choosing at random). Once invented, this innovative "practice" can spread through the population in three ways. Agents can "catch it" with some probability from those who already have it (observation), they can be born with it (reflecting socialisation by an innovating parent) or they have a very small chance to discover it without reference to network or socialisation (perhaps reflecting other forms of transmission like books.) The results are interesting. In the first place, unlike the last two experiments, there *is* a significant difference before and after the innovation (0.64836 and 0.462418). However, the result is recognisably negative. This is because, although on an individual level, choosing the least connected agent to make a tie to may seem like a good way to increase the size of the GC (by "incorporating" isolates), it actually results in a centralised network that is much more vulnerable to the death of some agents. Thus we see, even in a stylised example, the potentially counter-intuitive conflict between the logic of individual choices and aggregate social outcomes [18].

The previous discussions have been leading up to the third variant ABM, a very simple form of institutional growth. As we have seen, a GM cannot be great (in this ABM at least) just on the basis of his own actions. He must also, somehow, change behaviour, networks or institutions. Individual decisions, spreading through the population may actually harm the outcome they are intended to promote (in this case GC size.) How then can social order come about over long periods without assuming high levels of rationality or knowledge? This variant ABM provides one possible answer. In it, after a certain date, there is an innovation, but of a different kind to that already discussed. An agent decides that it will, before its death, seek a replacement for its position in the social network. In this case, other agents will consider whether replacing the existing agent or just making the usual random connection will lead to better connectedness. For simplicity the agent that wants to be replaced does not apply any selection criteria. Furthermore, there is no attempt to ensure that the replacement agent has surplus capacity to take on the ties of the dying agent. Instead, it just sheds some existing ties randomly to ensure that maximum tie capacity is maintained. As before, the social innovation of wanting to be replaced can spread

[18] As with all variants reported here, this is the result of ten simulation runs, averaging the giant component size over 4000 time periods (to allow for noise) at two points in the simulation (before and after the "event" whether that be innovation or a GM.) The only difference in this condition was that the measurement periods were 12000-16000 and 24000-28000 time periods. This was to allow time for the innovation to diffuse since that is a more protracted process than the life of a GM.

through the population. This gives rise to a situation where an institution consists of a set of nodes that all want to be replaced and the connections between them. Provided replacement actually occurs, this institution will reproduce itself over time. The final ingredient in increasing order is the assumption that if a node wants to be replaced but nobody wants to replace it (because that node is very poorly connected for example) then replacement will simply fail. This gives rise to an evolutionary process in which there is a continuous random variation in the population of nodes that want to replace themselves (which might include the innovative practice dying out again) but a selective retention of those that happen to be organized in ways that ensure that others want to continue replacing them. (Cliques – network structures where everyone is connected to everyone else – are a good example. Once they form randomly, agents have a strong incentive to replace because they instantly gain access to a large number of ties and everyone else in the clique is part of the same virtuous circle.) Using the same measurement procedures as before, there is again a significant difference between the GC size before and after the innovation of institution formation (0.65751 and 0.70427). However, unlike the case where agents started to choose the least connected partners individually rather than choosing at random, this social innovation has positive effects for the connectedness of the network.[19] Furthermore, these arise on the basis of individual decisions based on very limited information that gradually self-organise into a mutually sustaining institution.

4 Conclusion

Because the purpose of this article is to present case studies of ABM to start a dialogue about the potential of ABM for history (both in developing models that *will* appeal to historians and avoiding those that *won't*), there is a real danger that a conclusion will simply recapitulate the article itself. There is however one set of linked ideas that can usefully be presented as concluding this argument at this stage.

The hope has been to present ABM of three social processes that might be historical in the view of historians and which might be hard to represent and understand without ABM (a genuine social innovation, possible roles of unique individuals and the growth of a stylised institution.) There are at least three ways in which these ideas could be developed, all of them positive for dialogue between history and ABM. The first is simply additions to the list of potentially historical processes that could then be modelled. (If these examples are not, or are not exhaustively, what is meant by history then what do we need to add?[20]) The second is just to follow these ideas through in more detail and explore their consequences. For example, we have shown the effects of single social innovations in a simulated society that has (by design) reached a steady state purely so we can present clear differences in GC size. But, in fact, societies may never reach a steady state and face

[19] Note that these effects are unintended. An agent wants to be replaced. This *happens* to increase the size of the GC. As with selection of least connected agents, it need not have this effect.

[20] As well as advancing modelling, this dialogue could thus help to clarify theoretical thinking in history in a way that narrative theorising might not.

more or less constant social innovation. Is an ABM the only way we can possibly characterise such profoundly dynamic systems? Finally, and this was hinted at in the discussion of the GM, we have so far treated each historical process as if were separate, purely for simplicity of exposition. In fact, of course, it is highly likely that these effects combine. Our GM had no lasting impact. But could he have done so if he had also introduced a social innovation in behaviour even if, without him, that behaviour could not have spread (or perhaps even worked?) Almost regardless of the actual findings of our ABM, we hope that we have both raised some cautionary notes for the style of existing "historical" ABM and suggested some new avenues for "more historical" approaches that might start a more effective dialogue with historians.

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