One Model, Multiple Stories?
Using Agent-Based Models to Unveil Structural Similarities in a Complex World

Dissertation

zur Erlangung des akademischen Grades Dr. rer. pol. an der Fakultät Sozial- und Wirtschaftswissenschaften der Otto-Friedrich-Universität Bamberg.

vorgelegt von

Daniel M. Mayerhoffer, M.A., M.Sc., M.A.

Bamberg, 2023

To all who have guided, supported, and accompanied me throughout the course of my education.

It is thanks to your contributions that I could start and finish this thesis, and I am grateful for every single one.

Bamberger Beiträge zur Modernen Politischen Theorie ; Band 3

Diese Arbeit hat der Fakultät Sozial- und Wirtschaftswissenschaften der Otto-Friedrich-Universität Bamberg als Dissertation vorgelegen.
1. Gutachter: Prof. Dr. Johannes Marx
2. Gutachter: Prof. Dr. Rainer Hegselmann
Tag der mündlichen Prüfung: 31.08.2022

URN: urn:nbn:de:bvb:473-irb-585782
DOI: https://doi.org/10.20378/irb-58578

Contents

1

Framework Paper

The author thanks Johannes Marx, Rainer Hegselmann and Dominik Klein for their valuable input and feedback on this framework paper.
Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - 430621735

Abstract

As part of a doctoral thesis, this framework paper precedes papers from three Agent-Based Modelling research projects. Each of these projects developed a model structure and transferred this structure from one application case to another. The paper argues that such transfer of the structure of an Agent-Based-Model from one real world application to another is indeed possible by means of story adaptation to the new application case. If successful, the transfer benefits research in two ways: (I) It improves efficiency for modellers and readers alike; (II) it can reveal structural similarity between these cases and help to assess the extent of this structural similarity. Therefore, structure transfer is no mere auxiliary to Agent-Based Modelling but an independent scientific endeavour. However, such endeavour may also fail or mislead in the sense that an identified structural similarity between two modelled situations does not exist. Hence, model structure transfer requires a careful execution. Finding insights about structural similarity can further enrich Agent-Based Modelling as a method, Political Science when it applies this method, and Political Theory in its capacity to link different research programs or inspire new ones within and beyond Political Science. The major arguments apply to any method that aims to study complex (political) systems and applies beyond the academic domain also to complexity practitioneers in government bodies, companies, or NGOs.

Keywords Agent-Based-Modelling, Computational Social Science, template transfer, complexity, validation

Contents of this Paper

1.1 Introduction

In the CoViD-19 pandemic, various phenomena of interest for political theorists have surfaced. Besides content-related observations, for example, legislative and executive processes in extraordinary circumstances, patterns of international (non) cooperation or citizens' reactions to perceived cohesion, two methodological aspects strike the eye of those interested in policy modelling. Firstly, a range of different simulation models have become publicly known as tools for a (scientific) explanation, prediction, and teaching: Different models are applied to national, regional or local contagion scenarios; different models incorporate different kinds and levels of empirical calibration by, e.g., real-world movement data or conditional assumptions about individual hygiene; and different modelling approaches, ranging from large-scale differential equation models to track system dynamics to granular Agents Based Models (ABMs), complement each other. Secondly, embattling the novel virus and disease required learning from other situations that feature different circumstances or specifics but are similar in structure to the CoVid-19 case: Knowledge about other coronaviruses facilitated a quick description of SARS-CoV-2 and its variants and both the developers of novel mRNA vaccines and "classical" dead or vector ones stood on the shoulders of giants which gave them a significant kick-start. Concerning non-pharmaceutical interventions, structural similarities were also exploited in applying knowledge about the spread of other diseases or even from marketing to the novel pandemic. This last aspect combines simulation models and structural similarity to provide practical policy advice but also to understand and explain the real-world pandemic - and, on a less pressing note, to uncover structural similarities between seemingly different situations, like the Spanish flu and the CoViD-19 pandemic.

While the use of models, as well as the exploitation of structural similarity, have helped a lot in fighting the pandemic, they have also experienced some distrust from the public and methodological problems. For example, scientists have failed to predict herd immunity correctly, and simulation-based predictions of daily cases were sometimes spectacularly wrong. Sometimes, these failures were due to changed circumstances in the real world (like new virus variants) or because policymakers and individual citizens had adapted their behaviour in light of the assertions made by modellers (like imposing new curfews) and hence rendered the model assumptions wrong. However, sometimes the model assumptions have not resembled reality sufficiently (like people not reducing their contacts), or presumed structural similarities (e.g. between countries) have failed to hold. A potential reason for this failure may be that, despite its frequent exploitation in academia, business and public decision making, a presumed structural similarity is rarely made explicit, let alone treated as an independent research target. Thus, a methodological reflection on structural similarity in social and political modelling seems overdue.

This framework paper attempts such a reflection. It explores the capability of employing similar model structures in different applications to uncover potential structural similarity of the corresponding real-world scenarios as well as efficiency gains for modellers. When modellers build on the assumption of structural similarity between situations of different content or context, they should explicate and discuss that assumption. With this, structural similarity can become a source of knowledge about our complex reality. However, the paper warns against pitfalls that may lead to identifying and exploiting similarities that do not actually exist. It focuses specifically on the method of Agent-Based Modelling since it uses the three papers mentioned above as examples, but also because the method has received growing attention in the 21st century in Political Science (Kollman & Page 2006) and is well-established there by now (de Marchi & Page 2014). In contemporary Political Theory, ABMs present a computer-aided form of "Mental Models" (Gaus 2013, p 82). Hence, a better understanding of structure transfer as one aspect of Agent-Based Modelling will benefit political theory regarding its own methodological toolkit and as a reflective authority on the methods of both political science and practice. Moreover, the findings presented in this paper apply to other theoretic, simulative and empirical methods and other disciplines, too.

The methodological discussion in this framework paper ties the three simulation papers together that the present doctoral thesis comprises. They originate from research projects that have started to utilise structural similarity in ABMs before the pandemic. Asgharpourmasouleh et al. (2019) study different protest movements in Iran and Germany using the same model structure but with different assumptions and attributing slightly different interpretations - or stories - to some elements. Schulz & Mayerhoffer (2021) themselves only feature one model about industrial innovation dynamics, but its very structure with an entirely different story is used to track discursive patterns in crises in a forthcoming article. Finally, the structure of the model in Mayerhoffer (2018), which captures the evolution of adolescents' stance towards queerness in a single generation, is extended in another forthcoming article for application to a broader range of values and to capture inter-generational impact patterns in a longer period.

The remainder of this paper is structured as follows: Section 1.2 introduces complex systems and argues that structural similarity between systems is widely though often implicitly accepted. Section 1.3 presents ABMs as a fruitful and flexible approach for the study of these complex systems and as a common tool in Political Science. Section 1.4 presents the idea of model structure transfer, whose realisation Section 1.5 discusses in detail. Section 1.6 presents the three thesis papers as examples for doing so. Finally, Section 1.7 highlights potential pitfalls of the practice and Section 1.8 makes concluding remarks.

1.2 Understanding Complex Systems by Means of Structural Similarity

In line with Buckley (1967), this paper understands present-day closely connected societies as complex adaptive systems; they appear in an interplay of political, economic, social, cultural and other spheres, which themselves can be seen as complex systems.[1]. Such systems show interdependencies be-

[1] This understanding is similar to Luhmann's (1997, p 746) account of a functionally differentiated society (Martens 2000) because he assumes: "Indeed, all functional system are linked together and kept within the real of society via structural linkage." ("Faktisch sind alle Funktionssysteme durch strukturelle Kopplungen miteinander verbunden und in der Gesellschaft gehalten.") For (Luhmann 1997, p 779), elements (or subsystems) within a system are interconnected and influence each other (Schimank 1997, 2005). Indeed, this interpretation may stretch Luhmann, but (Schimank 1999, p 416) explicitly uses the example to introduce his instrumental approach to grand theories and illustrates this as follows: "How does Luhman's concept of structural linkage of autopoietic systems contribute to

tween the heterogeneous individual entities that are part of the system and act within it.

1.2.1 Emergence, Mechanisms, and Structure

It is impossible to give an exhaustive and uncontroversial definition of complexity or complex adaptive systems[2] , as, e.g. (Gerrits 2012, p 49) notes: "There are about as many definitions as authors are writing about complex adaptive systems." Thus, the following paragraph does not aim to provide a complete account of a complex system but concentrates on emergence as a critical feature and its underlying mechanisms in their structural embedding.

Effects observed at the macro-level of the complex system are regularly non-linear or even non-monotonous because they emerge from the micro-level; the elements composing the system display individual behaviour and structured interaction that result in the observable macro-level phenomenon. Often, one cannot establish a straightforward relationship between the system and the sum of individual actions. Instead, aggregation involves sensitivity to regularities that govern the micro-level and interaction between individuals so that "'derived' dynamics can be found." (Holland 1998, p. 201) For example, the patterns found after movement dynamics in Schelling's (1969; 1971; 1978) checkerboard model of segregation have finished are more segregated than the mild individual preferences for segregation would imply. From the macro perspective alone, these derived dynamics appear inexplicable because they seem to emerge out of nowhere; from the micro perspective alone,

understanding interaction between individuals? At the end of the day, it does not matter for such an instrumental approach to grand theories whether the concepts found there are hermeneutically properly used or more or less distorted. Creative mistakes are allowed to happen. The instrumental approach may utilise whichever useful tools it finds from here and there without restraint and should not shy away from combining tools from incompatible theory traditions." ("Oder wie trägt Luhmanns Konzept struktureller Kopplung autopoietischer Systeme dazu bei, Interaktionsprobleme zwischen Personen zu erhellen? Einer derartigen strikt instrumentellen Nutzung der grand theories kann es letztlich egal sein, ob sie die dort gefundenen Konzepte im hermeneutischen Sinne richtig verwendet oder mehr oder weniger verfälscht. Kreative Irrtümer dürfen passieren. Und eine instrumenteile Nutzung darf sich auch hemmungslos überall bedienen, wo sie brauchbare Werkzeuge findet, und muß keinerlei Skrupel beim kombinatorischen Einsatz von Werkzeugen aus inkompatiblen Theorieperspektiven haben.")

[2]Note that complexity is not limited to socio-economic systems, but in fact, the term first arose in the context of physical ones. Complexity science embraces such systems as dynamic, unpredictable and multidimensional (Ladyman et al. 2012).

they seem meaningless because the emergence as their consequence remains unobtainable.

Therefore, one must constantly change perspective between individual and system levels to tackle emergence.[3] The mechanism-based approach (Epstein 1999) pursues this idea. Thereby, a mechanism-based explanation answers to 'why' questions. "Usually, and always ultimately,' this takes the form of citing an earlier event as the cause of the event we want to explain, together with some account of the causal mechanism connecting the two events." (Elster 1989, p 3) Hence, a mechanism fills a gap in the covering law account; this account cites the ingredients of an explanation but treats how they work as a "black box" (Elster 1989, p 7). Nevertheless, each black box consists of systemic relations with other black boxes and mechanisms are the rules that govern these relations. Focussing on mechanisms regularly means a micro-level investigation of phenomena that appear to be opaque at a macro-level. Hence, there are multiple levels of observation and what is the micro in one view may be the macro in another. Thus, black box explanations meet the core idea of a systems-perspective on society (Buckley 1998, p 78): "A systems view of reality allows one to see that it is made of successive layers of bonded elements, each layer with properties of the previous one".[4]

In complex systems, mechanisms of different kinds are linked together and form networks. Hence, "the mechanism has a structure. When a mechanism-based explanation opens the black box, it discloses this structure. It turns the black box into a transparent box and makes visible how the participating entities and their properties, activities, and relations produce the effect of interest." (Hedström & Ylikoski 2010, p 51) Consequently, an investigation of complex social systems is the investigation of their structure.

[3] *Coleman's Bathtub* (Coleman 1990, pp 8,10) explicates the relationship between micro-level and macro-level. Thus, it presents a way of systematically evaluating emergent phenomena, which is especially useful when characterising an ABM (Klein et al. 2018).

[4] One can express this again in terms of the understanding of social systems that claims a "co-evolution of societal evolution and evolution of subsystems" ("Co-evolution von gesellschaftlicher Evolution und Teilsystemevolutionen") expressed by (Luhmann 1997, p 565).

1.2.2 Usage of Structural Similarity between Complex Systems

In further elaborating on the above quote, Gerrits state: “Each domain, and perhaps even each instance in which systems thinking and systems theory are developed and applied, necessitates a tailor-made definition. There is no unified system theory that is broad enough to capture all systemic properties and diverse enough to capture the rich detail of particular instances.” One might mistake this to suggest that each complex system is singular and that no systematic structural similarity exists between any two systems or that one cannot track and analyse such similarity in a meaningful way. However, this conclusion is false from a theoretic and pragmatic perspective.

In terms of theory, Gerrits pointing to context-dependent understandings of complexity proves that authors recognise some shared features of systems within their application domain. That the salient aspects of complexity differ between domains per se more likely testifies to differences between these domains and not to the incommensurability of one complex system to another. More importantly, if a complex system consists of infinitely many interrelated subsystems at micro-levels, one will inevitably find similar structural elements in various systems when only digging deep enough. This is no mere ontological possibility but frequently happens in scientific practice because it lies at the core of the general applicability of the scientific theory. Thus, (Hedström & Swedberg 1998, p 10) underline the necessity of mechanism-based explanations to rest on shared features instead of case-dependency: “It is important to note that the mechanisms referred to in the foregoing discussion are mechanisms of some generality, and it is this generality that gives them their explanatory power. Simply making up an ad hoc story tailored to a specific case does not constitute an acceptable explanation.”

People who work with or on complex systems as scientists, in business or in the public sector have long recognised the structural similarity of systems and utilise this for various purposes; to name just a few academic and applied examples: In industrial economics Malerba & McKelvey (2018) investigate management decisions about research and development assuming similarity between different firms and economies, Damascelli (2004) build on shared features of solids to study their electronic structure experimentally, Schelling (1971) claims to capture social segregation along various features like race, religion, sex or age with an identical model. Parnas et al. (1984) advocate a modular approach to software engineering in order to reuse some modules in different contexts, thereby presuming similar underlying structures in these contexts. Complexity sciences also give their analyses of new explananda a head-start by drawing from existing explanations, as Gerrits (2012, p 72) explicitly refers to a "Case Pars Pro Toto". Moreover, the assumption of structural similarity between individual systems underlies approaches to teach practitioners about complexity (Sterman 1994), or manipulate the system (Checkland 2000; Checkland & Poulter 2010).

Therefore, the existence of structural similarity between different complex systems is generally accepted for it forms the basis of research into specific systems. The motive behind the practice is typically an efficiency gain, as Parnas et al. (1984, p 260) explicate for the case of software as a complex system: "The primary goal of the decomposition into modules is reduction of overall software cost by allowing modules to be designed and revised independently." However, besides this frequent exploitation for better understanding or using an individual system, such structural similarity between prima facie different systems also constitutes an interesting research target itself.

1.3 Agent-Based Modeling as a Method for Complex Political System Investigation

In light of the complex nature of society, (Farmer 2016, pp 15-16) demands: "We have an increasing need to model ourselves." Agent-Based Modelling has established itself as a tool for investigating complex systems that require micro-founded evaluation (Dijkema et al. 2013; Deckert & Klein 2010; Hegselmann & Flache 1998). This type of modelling is mainly used when the focus of a question is not the stability of an equilibrium or the assumption that a process returns to an equilibrium, but the question of how a system can adapt to changed framework conditions (robustness) or how macro-level phenomena emerge from micro-level mechanisms and thereby tracking how the underlying processes unfold (Epstein 1999). For example, one may employ an ABM to analyse the system's dependence on parameters that influence the actors' actions or to predict the future behaviour of the system based on the status quo.

For Political Scientists, Agent-Based Modelling presents a way of policy evaluation (de Marchi & Page 2014; Bavel & Grow 2016). One can apply ABMs both as a stand-alone tool and for pilot experiments in preparation for empirical studies (Gilbert et al. 2018). Thereby, application cases also extend to Political Theory where ABMs contribute to a reconciliation of large-n interaction situations with a Rational-Choice approach and thus further positive as well as normative Theory, e.g. social contract theory (Gaus 2017), or an understanding of self-governance in complex societies (Gaus 2021, pp 228-230). Moreover, ABMs are potential tools for politicians or policy advisors because they can facilitate decision making (Calder et al. 2018; Schmolke et al. 2010), integrated policy design (Meisser 2016; Gilbert et al. 2018), stakeholder engagement (Johnson 2015), or risk assessment (Dubbelboer et al. 2017), not only in the introductory CoViD-19 pandemic examples. Consequently, (Gilbert 2019, pp 77-78) explicitly introduces ABMs for Public Policy. Hence, a deeper understanding of Agent-Based Modelling is vital for Political Scientists not only as a research tool but also as a research subject. They should be aware of specific techniques among practitioners - like applying an existing model structure to a new scenario for efficiency reasons - to monitor and ideally steer their further development. Many of the examples cited in this section thus stem from various sub-disciplines of Political Science or policy practitioners.

An ABM represents the relevant entities of a real-world complex (political) system as its eponymous agents.[5] Simulating this model (typically aided by a computer) allows simultaneous observation of the system behaviour, the agents‘ actions, and dynamic interaction. Therefore, Agent-Based Modelling allows selective opening of a black box and is ideal for giving a mechanism-based explanation (Hedstrom 2005, pp 24-27). Namely, building an ABM

[5]Not all entities involved in a simulation must be modelled as agents. They can also enter the model as constraints to actions or input factors. However, those entities taking part in the interaction process that the model intends to capture will typically be featured as agents.

embraces the insight that explanation of most phenomena requires a stepwise approach (Hedström & Ylikoski 2010) and constantly switching between micro and macro-levels in heterogeneous systems. Like other simulation approaches, ABM seeks to represent a real-world system - or a variety of systems - to track the phenomena surfacing within it. Given the model's validity, insights gained from it will contribute to understanding the real world.

1.3.1 Ingredients of Agent-Based Models

ABMs track[6] the dynamic development of the system they model through agents' actions and interactions with each other or an environment. Expressed in Coleman's (1990) framework, the model mechanisms transform an initial state of macro-level parameters to a final one. The initial situation implies the circumstances for agents‘ actions on the micro-level. The model must also specify the micro-level environment to specify what a macro-level situation means for individuals. Individual actions, in turn, constitute the transformation. The aggregation of the agent-specific actions results in the new simulation state.[7] Thus, in line with Coleman's (1990) concept, the core processes in an ABM occur at the micro-level, i.e., within agents.

While an agent is the most basic unit of observation in an ABM, it is not necessarily a monolithic block but may itself employ complex internal processes to reason, decide, act and react to its environment (including other agents). The concept of an agent does not specify the level at which agents

[6]There are different accounts of how this tracking works precisely for ABMs and other models in the social sciences.: Some view them as tools for conceptual exploration without empirical commitment (Hausman 1992, p 77) or specific form of theorising (Weisberg 2007); others understand them as fictional texts (see Suarez (2009) for various accounts on this metaphor) like fables for understanding broad concepts (Rubinstein 2006; Johnson 2020), parables (Cartwright 2010), novels (Sugden 2000, 2009), or stories in general (Gibbard & Varian 1978); others again claim that models are indeed experiments (Mäki 2005) or related scientific tools (Knuuttila 2011).

[7]Typically, multiple actions and interactions take place sequentially or iteratively. Often, ABMs represent this iterative development based on discrete-time periods, whereby an initial state at the beginning of the period transforms into a final state at the end of the period. Breaking down a larger process into smaller junks often helps to understand the modelled system better even without simulating it and the periods approach also makes it easier to keep track of simulation results. Yet, one should bear in mind that ABMs can also feature continuous simulation or focus on a sequence of events instead of a timer; moreover, some ABMs also model only a single step where solely initial conditions matter for the simulation outcome.

exist in absolute terms. Instead, this level is the micro relative to another one, the macro, which shows the emergent phenomena caused by the agents‘ behaviour. To illustrate this, consider several cases of entities that serve as agents in ABMs. Most intuitively, these are individual people in their function as e.g. citizens (Klein & Marx 2017), voters (Fowler & Smirnov 2005), moral subjects (Hegselmann & Will 2010), consumers (Scalco et al. 2019), or employees (Pluchino et al. 2010). Moreover, a collective entity that one ABM treats as an agent in its analysis of some higher-level system may thus be the system level of another ABM, which specifically studies the emergence of the said collective entity from the interaction of its members. For example, one can also investigate collective agents - ones that consist of multiple individuals - like inter alia households (Schelling 1971), firms (Liu & Ye 2012), political parties (Plümper & Martin 2008; Laver 2012; Moya et al. 2021), military squads (Cioppa et al. 2004) and players in civil wars (Duffy et al. 2019), or research institutions collaborating to win grants (Ahrweiler et al. 2015).[8] Likewise, one may treat an individual person as macro-level whose behaviour emerges from the interaction of the person's body or mind parts; these body or mind parts could be treated as the agents in this case. Here, (McConnell 2010) provides an example of a conceptualisation that one may implement in such an ABM. A combination of different types of agents is also possible, e.g. energy consumers, suppliers and grid operators, to evaluate potential renewable energy policies (Deissenroth et al. 2017).

Irrespective of what they represent in specific models, the received descriptions of agents in an ABM[9], e.g. Wooldridge & Jennings (1995), Macy & Willer (2002), (Epstein 2006, pp 51-52) or Conte & Gilbert (1995), share three core features of agents: (I) Agents are autonomous, i.e., they can perceive and act independently. (II) There are some rules that govern agents' perceptions, beliefs, and actions, and these rules often mirror some form of intentionality. (III) Agents mutually influence each other based on some local[10] interaction

[8]From this list, the immediate relevance and applicability of ABMs for man Political Science topis is evident.

[9]The term *agent* appears in the literature on (computational) Agent-Based Modelling in a multitude of possible interpretations and concepts (Franklin & Graesser 1997).

[10]Locality can manifest itself in a spatial sense of the geographical neighbourhood as in Cellular Automata, or by random movement and encounters, but also in a network structure; and sometimes agents may even consider the whole population their local vicinity.

rules.[11] The first feature is a prerequisite for Agent-Based Modelling to be possible, the second refers to agents' internal behavioural models, and the third hints at aggregation in an ABM. Thus, the following paragraphs detail the latter two aspects.

The ABM represents any internal processes of an agent that govern individual action, belief updating, or even model entry/exit by its behavioural rules. Thereby, it does not matter whether these internal processes are mental in the case of a single person or some group decision making procedure in the case of collectives.[12] Commonly, the processes involve some kind of purposive action involving an explicit goal pursuit - often in rational choice procedure - but this is not necessary (Flache & Macy 2011). Indeed, any form of action principle including, as clarified by (Weber 1984, p 155), e.g., norm compliance and irrational action, is possible here. As a prerequisite for acting, agents must typically form beliefs about their current action context, which in turn means perceiving their environment and interpreting it by whatever means they are given by the modeller. This idea of a behavioural model is in line with Dennett's (2017) intentional stance or explanation that characterises actions by the desires, beliefs, and cognitive processes from which they result and focuses on the mechanisms governing them (Bechtel 1985). Despite being simple, these individual behavioural rules lead to complex behaviour on an aggregate level and make the shift "From Factors to actors" (Macy & Willer 2002) meaningful.

To move from the micro-level to the macro-level, one must aggregate individual behaviour. This aggregation has a substantive dimension and a formal one. The substantive aggregation of individual agents' behaviour happens

[11]From a practitioner's perspective, these characteristics neither specify agents' properties concretely nor in which way model agents represent any real-world entities. ABMs are flexible tools adjustable to their respective application context.

[12]Indeed, abstract models (cf. Section 1.3.2 for a definition of abstraction levels in ABMs) can even represent various individual or group levels by their procedure and interpretation, thus depending on the context of the application. For example, the Hegselmann Krause Bounded Confidence Model (Hegselmann & Krause 2002) monitors opinion formation processes. When applied to scientific debates, its agents could be either individual scientists or research groups. In the context of political deliberation, agents represent individual citizens, and Hegselmann et al.'s (2015) or Scheller's (2019) extensions feature an agent type that may be understood as an interest group or especially influential individual. See Section 1.4.1 for a discussion of such cases and Section 1.6.1 for an example that is part of this thesis.

through interaction: An agents' behaviour - execution of an action - may (a) consider others and (b) affect them directly or via manipulating global state variables that the others themselves react to. By doing so, the action mediately alters the state of the system beyond its immediate impact. As (Russell & Norvig 2021, p 69-76) summarise, interaction behaviour ranges from immediate reactions to environment changes (e.g., Schelling (1971)) to purposive manipulation of others or the environment (e.g., Zollman (2005)) and learning from previous experiences . In some ABMs, agents' actions, be they interactive or not, amount to heterogeneous fitness levels and agents are selected for certain additional procedures, like reproduction or death.[13] Since this selection only becomes meaningful when amplified and related to the population as a whole (Axelrod 2000, p 117), it is also part of aggregation in a model. It is as vital as sometimes difficult to get the substantive aggregation right in model design, but during simulation and analysis, this aggregation aspect happens automatically and needs no explicit attention (other than validation). The formal dimension of aggregation concerns tracking the influence of individual behaviour on global variables (Gilbert & Troitzsch 2005, pp 8, 101). These parameters include aggregates of agent parameters such as mean values that one can straightforwardly calculate. More attention is required when the state of a model environment is tracked, e.g. to model resource depletion. Here, the modeller must choose whether the impact occurs after each agent's action or the impact of multiple actions (e.g., all of a period) are collected before their application to the environment. Moreover, formal aggregation is not necessarily linear, and the choice of the aggregation procedure should be a conscious one, too.

1.3.2 Models as Explanatory Devices for the Real World

Typically, an ABM aims to provide some insights about the real world because, following Sugden (2000), modellers develop models for prediction (including retrodiction), abduction, or explanation. The present argument focuses on explanation since finding and exploiting structural similarity will always be an explanatory endeavour regardless of the model's primary pur-

[13] Cf. p 28 for death and p 55 for reproduction in the famous sugarscape model (Epstein & Axtell 1996).

pose. If model explanations are to apply to a real-world target system, one must validate the model (Gilbert & Troitzsch 2005), i.e., argue why there is a resemblance between model and target Mäki (2009). Thereby, the goal is not to prove beyond any doubt that the model can act as a surrogate system but to moderate the uncertainties that an inferential leap brings (Morrison 2015, p 257).Sugden (2000; 2009) argues for inferences from models to the real world to be possible. He starts with the observation that in everyday life, as in science, inference from one situation in reality to another situation in reality is standard and considered to be of little concern. Following this, one bears the burden of the proof if claiming the validity of models to be generally impossible while world to world inferences are not.[14] Therefore, it is not the general concept of validity that modellers must defend but the validity of the specific real-world explanations for which they use a particular model. Thereby, the appropriate validation approach depends on the kind of explanation that the model attempts and the level of abstraction featured in the model.

One may derive how-actually or how-possibly explanations from a model. While how-actually explanations aim for identifying the actual mechanism driving the dynamics in a specific case, how-possibly-explanations provide mechanisms that could possibly bring about the explanandum in question (Reutlinger et al. 2018). Thereby, how-possibly explanations do not claim to identify mechanisms that currently exist in the real world. Instead, they should be understood as looking for mechanisms that could potentially cause the observed phenomenon. Grüne-Yanoff & Verreault-Julien (2021) defines two sub-classes of how-possibly explanations. For a good epistemically possible how-possibly explanation, the explanans must be able to be actually true and the cause for the observed empirical fact. To argue for this possibility, a modeller must carefully track the mechanism itself (not only its input and output) and compare the findings to empirical data.

Contrary to that, a good objectively possible how-possibly explanation identifies sufficient conditions that would, if in place in the real world, lead to the explained phenomenon. Put differently, objectively possible how-possibly

[14] Section 1.4.3 contains an evaluation of Sugdens argument and highlights that one could also understand it as a note of caution against uncritical world to world inferences.

explanations can be contrafactual or conditional claims whose applicability rests on changes in the initial conditions of the real world. Nevertheless, they can fail if additional changes besides the one cited in the explanations would be necessary, i.e., the specific features of the explained situation are inconsistent with a broader context on which the explanation relies or in which it is situated. This leaves an independent question of how the changes would come about in the real world that would allow for the objectively possible how-possibly explanation.

Concerning the abstraction level of a model, Gilbert (2019) distinguishes between abstract models, middle-range models and facsimile models. Abstract models study essential dynamics in general settings; they should reproduce the real-world structures that the modeller wants to explain. Validation will typically rest on sensitivity analysis, i.e., simulation-based on ranges and combinations of input variables and model world features beyond the intended application situations. Middle-range models also feature essential dynamics but zoom in on specific structures. Hence, dynamics in middle-range models should qualitatively reproduce the corresponding real-world dynamics. Facsimile models execute specific dynamics in specific structures. For them, a quantitative comparison of model output with empirical data from the real world is in order. The opposite holds, too: There is a correlation between abstraction level and kind of explanation: Abstract models tend to yield objectively possible how-possibly explanations, whereas facsimile models may allow for how-actually explanations.

However, the correlation between the abstraction level and the intended explanation is not perfect. Hence, one must reflect on both these model features in question in mind when validating a model. Moreover, one should view validation as an ongoing process rather than a singular task (Squazzoni 2012, p 151). As such, validation starts with designing the model calibrating it empirically or theoretically; it entails verification (often called internal validation) which ensures that the technical model implementation and analysis do what the model concept or specification require and what the interpretation presumes, i.e. there are no bugs in the code. Validation ends with evaluating the plausibility of the output in line with one's expectations or some data. Thereby, the sources of the validation background - the real-world data - are as diverse as the field of agent-based modelling and are not limited to quantitative data (Fagiolo et al. 2019; Windrum et al. 2007; Yang & Gilbert 2008), and may simultaneously draw from multiple sources (Badham et al. 2017).

Overall, ABMs are helpful tools to study real-world complex social systems. To do this in a meaningful way, ABMs need validation: One must make plausible that the context in which the model was developed resembles the context for which the explanation is meant to hold. A similar notion is essential to ensure sensible model structure transfer that yields insights into structural similarity in the real world.

1.4 The Concept of Structure Transfer in Agent-Based Models

Section 1.2.2 argued the frequent usage of presumed structural similarity of complex systems for their study. Applying an existing model structure to a new application case is technically and conceptually easy with ABMs, but this ease may fool one into believing it is always unproblematic. However, a transfer must make sense, i.e., the model structure must be valid for the new application case. Before turning to the validity in practice (Section 1.5, exemplified in Section 1.6) and its limits (Section 1.7), this section explains that a valid transfer is indeed possible if executed carefully because model structure transfer is possible in principle as a specific case of template transfer. To this end, one must first understand the dual nature of ABMs as consisting of a structure and a story element.

1.4.1 The Structure and the Story of Models

Gibbard & Varian (1978, p 666) characterise a model as follows: "A model, we shall say, is a story with a specified structure: to explain this catchphrase is to explain what a model is. The structure is given by the logical and mathematical form of a set of postulates, the assumptions of the model. The structure forms an uninterpreted system". In addition to these structural elements, in a model, "there is always an element of interpretation: the model always tells a story. If we think of the structure as containing uninterpreted predicates, quantifiers, and the like, we can think of the story as telling what kind of extension each predicate has and what kind of domain each quantifier has.” (Gibbard & Varian 1978, p 666) Only its duality of structure and story makes an ABM[15] a helpful tool: The structure aspect requires a formal, precise expression of the modelled object and allows for in-depth tracking of what happens during a simulation and hence close mechanism-based explanation in and about the model. At the same time, the story ensures that these benefits of the structure do not result in a mere intellectual exercise but relate to the real world in a meaningful manner.

Other classifications separate models from their descriptions. These descriptions then present assumptions of what the model captures (Suppes 1960), interpret and identify the model subject matter (Giere 1988), or specify it Weisberg (2007). One can align those notions with the structure-story account of models, for what they view as a model appears to be the model structure, and the description element can be understood as the model story. Humphreys (2004, pp 102-103) further details the notion of (computational) models, but his six elements can also be categorised under the structure or the story of a model: The template, construction assumptions, and correction set belong to the model structure, while the interpretation and the (initial) justification make the story, and the representation joins both together.

Morgan (2001) adopts Gibbard's and Varian's notion of structure and story to further flesh out her concept of *Models as Mediating Instruments* (Morrison & Morgan 1999) for economic models: The structure of a model allows for manipulation as experimental conditions do. In contrast, the story of the model establishes its external validity: “We expect these stories to be related to our questions about the world, our typical experience of the world, and to the kinds of events we find in our world. [...] It is by telling stories about the economy that we most effectively connect our models to the facts of the

[15]Note that (Gibbard & Varian 1978, p 665) explicitly limit themselves to economic and theoretical models: “Our emphasis here will be on the use of models by that group of economists known as ‘economic theorists.’ Large-scale econometric models programmed on computers are the major tools for forecasting the performance of an economy, but about them we shall have little to say.” However, the econometric computational models of their time were multivariate regressions whose solution required computer-aided (Love-Koh 2019). Hence, one does not do them injustice by subsuming ABMs under their notion of theoretical models and their ideas also straightforwardly apply to other social sciences, too.

world." (Morgan 2001, p 197) Since inferences from a model to the real world are possible because the model specifically targets a real-world situation and is tailored toward it, alterations in this story can gear the model toward new applications scenarios even if the structure remains largely untouched. For external validity in the new application case, the story must sufficiently relate to (a) the new real-world scenario and (b) the model structure. Condition (a) is achievable in principle by thoroughly validating the model in its new application. Condition (b) requires some degree of flexibility in the structure-story relation of a model; the same flexibility is necessary when changing a model structure as to learn from building the model and analysing its output (Morrison & Morgan 1999, pp 31-34). If one can alter the model structure keeping the story intact, and retain a working model, the same should be possible the other way round, for the result seems irrespective of the source of the alteration.[16]

Overall, one can regard different stories or interpretations attached to a fixed structure not as different models but merely as one single model that can be "amazingly rich in interpretations" (Koopmans 1957) - or understand the result of story modification as a new model or Therefore, while story changes are a different procedure than structure modification or model development from scratch, the resulting ABMs will not necessarily differ. Sections 1.5 and 1.7 present a technical answer to this objection by establishing ideas of what story changes ought to look like in practice. For now, it is sufficient to accept that multiple stories can address one model structure,[17] as (Gibbard & Varian 1978, p 667) establish: "Sometimes it will be found that two models, with two different stories, have the same structure, or that one model has the structure of the other and some additional structure as well."

[16]Related to this, the idea of deidealisation of models presumes these models to be of a composite nature that one can split up and work with separately (Knuuttila & Morgan 2019).

[17]Of course, a real-world story may have different potential underlying structures. Indeed, scientific disagreement like the debate between mainstream and heterodox economics (Dequech 2007) partially originates in scientists attaching different structures to a story about the real world. However, this paper does not investigate the challenges and benefits of this extant multitude of model structures.

1.4.2 Template Transfer

As introduced above, Humphreys (2004) introduces the notion of templates as part of models. They tie together formal - structure - parts and interpretation - story - elements. He understands them to be representation devices that describes relationships between entities, e.g. competing firms or parties. There are theoretical/mathematical and computational/numerical templates, whereby the latter cannot be straightforwardly be derived from the former. Instead, one typically loses potential in analytical solutions and general applicability when constructing a computational template, meaning that the result becomes situation-specific (Humphreys 2004, pp 663-665). ABMs utilise these computational templates, but their granular notion and explication of interaction embrace the situativity implied by the template as an asset rather than a problem (Humphreys 2004, p 130). Its high degree of formality allows a template transfer from one subject domain or application case to another. Thereby, one establishes relations between the source and the target domain entities. The transferability relies on both systems having a similar structure, not on the similarity of the specific subject matters (Humphreys 2019).

However, template transfer is sensitive to the original justification of a formal structure in its application context, i.e. the story of a model. While template transfer naturally situates a formalisation in a new environment and attaches a new interpretation, it must not treat the formal aspects as given and readily applicable. Thus, template transfer includes an account for why the existing justification (i.e., story) applies to the new target domain or requires a newly developed justification for this domain.[18] If this condition is fulfilled, templates constitute a valuable source of or vehicle for knowledge transfer within and across scientific disciplines (Knuuttila & Loettgers 2016).

Overall, the literature on template transfer views templates as more abstract than models and as formalised yet loaded vehicles for modelling the new application context. On this account, template transfer makes existing tools and knowledge available in new contexts. Transfer of model structure extends

[18]Note that this account assumes the detachability of structure and story of a model discussed in Section 1.4.1 and differs from Houkes and Zwart (2019, p 100), who maintain that "modellers retain elements of the interpretation of the template and therefore do not take it as a merely formal structure."

this notion in light of the structure-story duality of ABMs that allows for the acquisition of new knowledge about the structural similarity of the model application cases by means of the transfer itself. Furthermore, to the best of our knowledge, the literature on template transfer does not discuss extensively by what means templates travel, i.e., what kind of action the transfer is. In the case of template transfer as model structure transfer, Section 1.5 argues that the execution of the transfer - and the potential modifications that come with it - constitutes genuine model construction. Thereby, model structure transfer can also build on structural similarity at the core of model to world inferences, as discussed in the following.

1.4.3 The Need for Cautious Model to Model Inferences

Section 1.3.2 introduced Sugden's argument for the permissibility of model to world inferences in light of the widely accepted world to world inferences. This section further explores said argument to call for caution when making inferential leaps like the ones implied by model structure transfer.

(Sugden 2000, p 24) illustrates: "Inductive inferences are most commonly used to take us from one part of the real world to another. For example, suppose we observe racial segregation in the housing markets of Baltimore, Philadelphia, New York, Detroit, Toledo, Buffalo and Pittsburgh. Then we might make the inductive inference that segregation is a characteristic of large industrial cities of the north-eastern USA, and so form the expectation that there will be segregation in, say, Cleveland. Presumably, the thought behind this inference is that the forces at work in the Cleveland housing market, whatever these may be, are likely to be broadly similar to those at work in other large industrial cities in north east USA. Thus, a property that is true for those cities in general is likely to be true for Cleveland in particular. One way of describing this inference is to say that each of the housing markets of Baltimore, Philadelphia, New York, etc. constitutes a model of the forces at work in large industrial north-eastern US cities. These, of course, are natural models, as contrasted with theoretical models created in the minds of social scientists. But if we can make inductive inferences from natural models, why not from theoretical ones? Is the geography of Cleveland any more like the geography of Baltimore or Philadelphia than it is like the geography of Schelling's checkerboard city?"

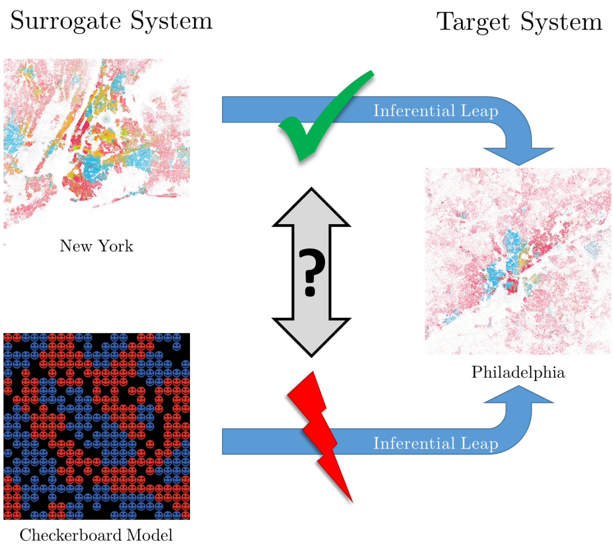

Figure 1.1: Incoherence between model-to-world and world-to-world inferences pointed out by Sugden

Figure 1.1 visualises this discrepancy that Sugden finds problematic because not epistemologically justifiable. In the above quote, he directly suggests a way to overcome the issue: One should follow the established, unquestioned practice of inference from one situation in reality to another situation in reality also when making inferences from a model to a situation in reality. This stance becomes apparent in a footnote to the above quote: "Notice that one implication of thinking in this way is that regularities within the real world (here, across cities which in many respects are very different from one another) can give us grounds for greater confidence in inductive inferences from a model to the real world." (Sugden 2000, footnote 20) Formally, Sugden's argument is as follows:

We deem the inferential leap $World_\alpha \Rightarrow World_\beta$ unproblematic.
$World_\alpha$ und $Model$ are structurally similar surrogate systems for $World_\beta$.
We should judge inferential leaps from structurally similar surrogate systems similarly.

$\therefore$ We should deem the inferential leap $Model \Rightarrow World_\beta$ unproblematic.

Central to Sugden's argument is thus the second premise, which proclaims structural similarity between a model world and a situation in reality. He supports this argument by introducing the idea of credible worlds, according to which a model constitutes a credible, because realistic, parallel reality in which a city exists as a parallel to Philadelphia as New York does. Credibility is derived from model mechanisms being in line with their (intuitively assumed, anecdotally experienced, or empirically tested) counterparts in the real world. Accepting this second premise, one could also reverse Sugden's argument: There is a need for caution with inferential leaps whenever we try to generalise knowledge about regularities, regardless of the type of test system. For example, significantly more Hispanics in New York and more Caucasian-Americans live in the city centre than in Philadelphia. Overall, this makes a knowledge transfer about residential segregation from studies in Philadelphia to New York questionable. Indeed, this lack of similarity between Philadelphia and New York does not make an artificial checkerboard city more similar to either. The model might provide a better proxy for understanding New York in some respects, while Philadelphia might do so in others. Put formally:

We deem the inferential leap $World_\alpha \Rightarrow World_\beta$ unproblematic.
$World_\alpha$ und $Model$ are structurally similar surrogate systems for $World_\beta$.
We should judge inferential leaps from structurally similar surrogate systems similarly.

$\therefore$ We should deem the inferential leap $World_\alpha \Rightarrow World_\beta$ questionable.

There are two main takeaways for model structure transfer from Sugden's argument. Firstly, structural similarity seems to be a vital feature for making inferences, and models can be inspected to identify the structure and hence structural similarity; such structural similarity is also applicable to the end of model structure transfer and its evaluation to explain the structural similarity in the real world. Secondly, like a model to world inferences require as much caution as a world to world inferences, similarities found by using similar model structures require as much caution as those found by applying one theory or empirical paradigm to different real-world cases.[19] However, such a requirement of caution is not to be mistaken for a warning against models identifying similarities altogether. Instead, modellers have an advantage here because they have gotten used to the need to validate their models; moreover, established tools and workflows for general validation come in handy for the specific case of validating structural similarity.[20]

1.5 Practical Ways of Structure Transfer

The multitude of application cases for ABMs and the different foci and levels of abstraction sketched in Section 1.3 imply various ways to apply an existing model structure to a new case. This section distinguishes such ways into three broad categories: First, straightforward application of a given structure and its technical implementation where only the story changes for a new case; second, slightly altering an existing structure to shift focus for a new application case; third, developing a meta-structure and then applying it to multiple individual cases. Table 1.1 provides a short overview of these categories. Of course, there is considerable overlap between the categories and a given transfer of structure may be put in a different category depending on which aspect of the transfer is emphasised. Nonetheless, the categories will be helpful to understand the kind and level of structural similarity that the model transfer can uncover.

[19] An apparent lack of such caution often prompts resentments against the transferring research, visible in inter alia the critique of so-called economic imperialism.

[20] Gräbner (2018) has pointed out that there typically is a trade-off between parsimony and proximity to empirical facts that lead models not to do equally well in all aspects of validation. The same holds for motivating structural similarity: For example, while one pair of models will formalise a similarity that is easy to grasp intuitively, another pair may have problems relating to this intuition but instead be able to pinpoint the similarity in empirical data.

Type of structure transfer	**Abstraction level of original model**	**Abstraction level of new model (compared to existing)**	**Efficiency gains through transfer**	**Insights about structural similarities**
Employ identical structure	abstract or middle-range, rarely facsimile	typically the same	very high	testing of presumed similarity
Extend/alter existing structure	any	same as or different	medium to high	establish-ment of structural context
Derive structures from metas-tructure	ab-stract/meta	any two	case dependent	concepts of potential similarity

Table 1.1: Overview over different model structure possibilies

In the interest of readability, the present paper - and this section especially - speaks of *original* and *new* application cases or scenarios for a model. This terminology might seem to suggest that a modeller will first develop the model with just the original application in mind; only after the model is finished, simulated and analysed will they consider transfers to the new case(s). Such a sequential approach is undoubtedly the most common one in structure transfer since it typically takes a proper analysis to understand the model, its mechanism, and potential additional application scenarios. These steps may not be needed to make the transfer, but insights gained in the original contexts often carry over, constituting an additional motivation for both analysis beforehand and the transfer itself. Moreover, after model publication, anyone, not only the original modeller, may use its structure, increasing the probability of a transfer. Nonetheless, it is also possible to plan for multiple cases when designing and implementing the model (cf. the example in Section 1.6.2). As structural similarity between models is symmetric, it is insignificant which application was first: if there is structural similarity, insights from one application case to the other are possible. The transferable insights are not limited to ones drawn from the ABMs themselves but also entail structural findings about one of the two scenarios that may apply to the other, too. Thus, in using model structure similarity to learn about real-world structural similarity, ABMs further enrich their role as instruments that provide guidance on interpreting existing data or theory or illuminate avenues for future research.

1.5.1 Employ an Identical Structure to Multiple (Structurally Closely Related) Cases

The first way of applying a model to different scenarios is to keep its structure untouched and solely alter the interpretation/story. This can shed further light on the structural similarity between real-world cases that feature parallel mechanisms. The model transfer can help identify the extent to which the parallelity does indeed hold and prompt reflection on how the cases differ. One may overlook structural similarities when investigating each case in isolation or because disparities at a superficial level cloud one‘s view of underlying structural similarities. The latter will often be the case when the new application case comes from a different field than the original one.[21] The structural reflection needed to develop an ABM also enables looking beyond these evident disparities and directs one‘s eye to mechanisms and structure even outside the original application case. Of course, this may also show that while the cases exhibit noteworthy parallels, they are not entirely identical but also differ structurally.

About model design and input, entities and their configuration stay the same from a technical perspective. However, they may mean something different in the new application case(s) than in the original one. Consequently, the new application case(s) may treat a different region of the model parameter space as realistic than the original one. Concerning simulation outcomes, the meaning of output values may diverge between the original and the new application case(s). Employing an identical model to two cases works out where and how they differ and why the differences matter. The resulting insights

[21] Consider, for example, structural similarities between ants in their colonies and traders in the stock market. One may not see them at first because apparent discrepancies - the macrostructure and individual characteristics like number of legs or intelligence - tend to supersede them. Yet, Kirman’s (1993) *ant model* bases its insights on said similarities.

benefit the understanding of a structural relation between the application cases and shed further light on the structure of each case.

When directly applying an existing model to (a) new case(s), the modeller will neither alter the code nor exogenous variables, i.e. the output also does not change, and there is even no need to rerun any simulation or (statistic) analysis procedures. Such an approach makes the technical aspects of the model design process much more efficient: One gets multiple models but must only code, debug, simulate the model, and develop and run the analysis only once. Additionally, other than for template transfer discussed in Section 1.4.2, there is also no need for developing multiple model concepts or multiple variants of a concept.

However, that does not mean that employing the model structure in additional cases comes without additional effort. The aforementioned differences between the application cases require specific justification and interpretation: One must specify which real-world entities the model entities represent for each application case and also justify this relation. Moreover, each application case requires a unique interpretation of simulation results. For example, a model parameterisation that intends to represent the status quo for one application case may represent a counterfactual in another case and vice versa. Hence, the simulation results for the parameterisation in question are to be understood differently for the two cases, too. These differences also imply a re-assessment of the level of idealisation for the new application case. When drawing normative conclusions from an ABM, one must consider that a particular model outcome that represents a desirable situation in one real-world case may be undesirable in another case.[22] Furthermore, the two application scenarios may be story-wise, closely related or detached. What matters is the validity of the proclaimed structural similarities, i.e. making sure they are reliable and not spurious (cf. Section 1.7).

[22]For example, cooperation may be good in political participation but problematic if it means cartelisation of firms.

1.5.2 Extend or Alter an Existing Structure to Cover New Application Scenarios

One-to-one application of an existing model and its parameterisation to a new application case is not always possible or desirable, even if there are structural similarities between the original and the new case. Often, the transfer of the model structure can pursue one (or more) of the following four goals: First, it can clarify the degree to which the cases resemble each other and hence presuming this resemblance would not be helpful. Second, modellers may want to generalise a situational that an existing model yielded for a specific question to a more general domain. Third, the transfer may situate an existing model which describes only a part of a system in the broader context, i.e. internalise previously external parameters. Fourth, the existing model may lack explication of some internal processes (treating them as constant parameters or as stochastic), and for a new application case, these internal processes demand a closer study. The modeller can take an existing model and alter or extend it to fit the new application case(s) to reach these goals. Put differently, model alteration or expansion always comes with a conscious investigation of structural similarities between the original application case and the new one; hence, working on the existing model contributes to conceptual clarity regarding structural relationships, too.

Having a running and ideally well-understood model as a point of departure for a new one makes coding and internal validation smoother. If one makes only slight changes to a model, especially if the core mechanisms remain unperturbed, one should expect the new model to be reliable, too. Moreover, the justification of specific input parameters and model mechanisms may also apply to the new application case. For example, the behavioural model governing individual consumption behaviour may apply to a model regardless of the products whose consumption a model studies. Nonetheless, careful external validation of the new model is in order; as part of this external validation, the modeller must also argue why reusing some parts of the previous model is appropriate in the new application context and how the changes made affect mechanisms in the model. To achieve the latter and to communicate the extended or altered model efficiently, it will be helpful to closely track all changes, i.e. document them when implementing any changes. Doing so also reduces the risk of bugs due to interactions between old and new model code.

Extension of an existing ABM will typically mean jumping to the implementation earlier than in model development from scratch: When there is something already up and running, one may feel the urge to start trying things out right away. However, modellers need to be cautious not to start implementing and interpreting results prematurely. Ad hoc modifications will often result in features of the new model that were easy to realise technically, i.e. required the least modification of the original model, not ones that bring reasonable resemblance between model and reality. Furthermore, a modeller must make sure that they know the model they intend to expand or alter inside out technically and conceptually. This applies when building on models developed by others but also developed by oneself. With this, even developing a model from scratch may be understood as a form of model extension if the modeller first implements a skeleton and adds the details step by step.

1.5.3 Derive Specific Structures from a Common Meta-Structure

As the last flavour of reusing an existing model structure to unravel structural similarity, one can employ a common meta-structure in multiple models. A meta-structure ought to be understood as implementing a given mechanism along with its underlying fundamental theoretical considerations. The meta-structure may find application in models of different disciplines as Marks et al. (2019) demonstrate for fitness landscapes that appear not only in biology but also in the social sciences. This example shows that derivation of specific structures from a common meta-structure can help identify how seemingly unrelated cases are related in some structural details. Sometimes, these details may be far-reaching, and the common meta-structure will govern the derived models almost entirely. How far this goes depends on the individual meta-structure and application cases.

A meta-structure alone is not a model, but it can be included in multiple different models. As for the structural similarity, the extent of fitting needed thereby depends on the meta-structure in question and the cases in which one intends to employ it. Sometimes, the meta-structure will govern anything but initial conditions in a model, including interpretation of the parameters. At other times, like the fitness landscapes mentioned above, the meta-structure will govern the model mechanisms but require individual structural interpretation for each specific structure. And again, in other scenarios, a meta-structure may be used to derive a specific sub-structure in an application case. Consequently, the extent of efficiency gains depends on how the derived structures relate to the meta-structure and one another. In any case, the derivation process itself will provide insights into the structural similarity of application cases.

1.6 Examples of Structure Transfer

There are three peer-reviewed and published papers in this doctoral thesis, and Mayerhoffer substantially contributed to all of them. These three papers employ distinct ABMs, and each of these ABMs utilises structure transfer, even though the product of the transfer appears only in one of the three papers directly while, with the other two examples, it is part of additional papers co-authored by Mayerhoffer. The following subsections provide extended abstracts of the three papers and highlight in which sense the corresponding research projects employ model structure transfer.

1.6.1 Stochastic Learning and Replicator Dynamics in Competition and Discourse Networks

This paper is joined work with Jan Schulz (University of Bamberg, Germany) and published in the *Journal of Business Economics* (2021). The authors contributed equally, and the order of authors was chosen randomly.

The paper proposes a parsimonious extension to the foundational agent-based model developed by Dosi et al. (2017) to explain the empirical distributional regularities or scaling laws of firm-level variables, like the extreme concentration of firm sizes and the high frequency of extreme growth events. The model does so by combining a purely stochastic learning process that models productivity growth with replicator dynamics that calculates a firm's current market share as the product of its past share and relative productivity.

Our extension introduces a network layer for the competitive interactions of firms, disentangling the effects of two modes of competition. the global competition for sales and the localised competition for market power for (imperfectly) differentiated products. While most of the distributional regularities are remarkably stable under this extension testifying to the robustness of our approach, we find that the empirically well-established combination of 'superstar firms' (Autor et al. 2019) and Zipf tail in the firm size distribution (Axtell 2001) is only consistent with a knife-edge scenario in the neighbourhood of most intensive local competition. Both phenomena are of high macroeconomic relevance, where Zipf's law has been linked to increased aggregate volatility (Gabaix 2011) and the emergence of 'superstar' firms to both increased income inequality and a falling labour share of income (Autor et al. 2019). Our model also contests the conventional wisdom derived from a general equilibrium setting that maximum competition leads to a minimum revenue concentration. In contrast, we find that the most intensive local competition leads to the highest concentration through Zipf's law and that the lowest concentration appears given a mild degree of oligopoly.

Since we are particularly interested in the dynamics of the socio-economic system that competition with industries constitutes, we employ Agent-Based Modelling. Given the high level of idealisation, we do not intend to make quantitative predictions but are confident that the model can illuminate central qualitative features of our economic target system Grüne-Yanoff (2009). Like its basis developed by Dosi et al. (2017), our model is micro-founded and evolutionary while - following bounded rationality Simon (1990) - exploring dynamics in the absence of rational expectations. However, our model introduces a network structure that represents competitive interactions between firms and adds a layer of locality to the core processes which the model studies. At initialisation, any two firms link to each other with a global probability p (where $p = 1$ represents the model by Dosi et al.). During the simulation, three processes occur iteratively: Firms improve their productivity by idiosyncratic learning; they divide the market based on prior market shares and productivities, and new entrants replace firms whose sales fell below a threshold.

These new entrants form links to incumbents with the same probability used for initial network formation. They start with industry-specific knowledge and opportunities: Their starting productivity is the average productivity of incumbents to which they are linked. This mechanism is consistent with 'entrepreneurial imprinting' or the notion that founding conditions strongly influence the survival probabilities of firms.

In the model, two mechanisms determine the productivity and, consequently, the sales success of a firm: Stochastic learning in connection with replicator dynamics that Dosi and colleagues study in detail shapes the outcome for a very dense and completely unconnected network. However, for sparser networks, it is essential to whom entrants link because this determines their initial productivity. For an entrant's success, connection to highly productive incumbents is vital, while connection to unproductive ones is detrimental. The sparser connected a network, the fewer entrants form connections to highly productive incumbents; hence, their initial productivity is low, and consequently, their market shares decrease – which explains the fat left tail and lower mean firm age. However, those entrants connected to highly productive incumbents strive because their initial productivity is not reduced by connection to many unproductive incumbents. Therefore, they can catch up with the most successful incumbents, and market concentration decreases. Our results suggest that the empirical findings are only consistent with a narrow parameter range representing a strongly connected network. Thus, our results suggest that the highly concentrated firm-size distribution in the upper tail and the 'superstar' behaviour is an emergent property of a situation with the most intense localised competition.

This research project embodies two instances of model structure transfer. Firstly, it extends the existing model structure proposed by Dosi et al. (2017) and provides context to the dynamics in the form of localised initial conditions. This localisation through an Erdős-Rényi random network structure (Erdős & Rényi 1960) is itself an application of a meta-structure. Secondly, in Mayerhoffer et al. (forthcoming), we employ the model structure to crisis discourse. Thereby, the model structure remains unaltered, but we change its interpretation (firms → discoursive position; productivity → perceived expertise). Consequently, the realistic part of the parameter space also changes while the statistic analyses of the parameter space as a whole did not need to be rerun.

1.6.2 Protest Dynamics in Iran and Germany

This paper is joined work with Ahmadreza Asgharpourmasouleh (Ferdowsi University of Mashad, Iran), Masoud Fattahzadeh (Ferdowsi University of Mashad, Iran) and Jan Lorenz (Jacobs University Bremen and GESIS, Cologne, Germany). It is published in the edited volume *Computational Conflict Research* (2020), edited by Deutschmann, Lorenz, Nardin, Natalini and Wilhelm. The authors contributed equally to the paper.

Social media are an important factor shaping the social image of a protest, as recent examples like the PEGIDA movement in Germany show. The paper investigates different fates of protests in the context of social media. It consists of a theoretical part, which explains their co-evolution and a computational model, operationalising the theoretical considerations and linking them with empirical data (partly from the literature and partly collected in the project).

Since social images are condensed public opinions on issues of general interest, they develop from the bottom up via individual actors' choices and interactions. Social media makes these interactions both easier to execute for individuals and harder to control or prohibit for governments. Given that usually a small number of citizens start a protest, its fate depends not only on internal dynamics but also on the social image of the protest: How a protest is perceived determines whether bystanders join it and which topics those who do join emphasise. Furthermore, protesters may change their own opinion in spite of their friends', colleagues' or family members' stances towards the protest. Thereby, messages sent from the protests to the public via social media and the perception and response to these messages influence each other. Hence, there is a second-order conflict in social media about the social image of a protest: Different actors try to gain prerogative of interpretation regarding what a protest stands for to push protesters towards certain positions or suffocate the protest. An example for new dynamics regarding protest perception and within the protest surface in the Iranian protest of 2017/18 that was initially driven by conservatives but quickly evolved into a liberal movement.

Therefore, it is vital to study the co-evolution of protests and their perception in social media. The paper does this using Agent-Based Modelling to compare and evaluate different theories on how street protests emerge, develop and eventually either succeed or fade away. Data for the study is retrieved from the aforementioned Iranian protests, which strive for democracy, and PEGIDA, which explicitly opposes - from its members' point of view an inadequate form of - democracy.

The simulation results suggest that citizens' general disposition to take their concerns to the street is the first aspect of different protest fates. Secondly, the social and political context also plays an important role: It determines how successful a protest is and how easily it can be allayed with concessions. Different combinations of these factors explain why each protest situation develops individually.

The goal of the comparative simulated case study was to understand the structural similarities between the two protests and to identify the differences that caused the diverging superficial fates of both protests. Thus, the model is an example of altering an existing structure by changing the parameters between the German and the Iranian case. Thereby, the alteration was no separate development step because both models - or model settings - were built concurrently.

1.6.3 Adolescents‘ Value Development Specifically Regarding Queerness and in General, Short-Term and Long-Term

This paper is single-authored and published in *Historical Social Research* (2018).

It focuses on the highly emotional debate in Germany regarding what to teach children about LGBTQ people: Christian Conservatives, Christian fundamentalists and others advocating a heterosexual, cisgender norm fear an indoctrination of adolescents to become more open towards LGBTQ people. At the same time, promoters of sexual plurality complain that the church is an institution that undermines and marginalises the interests of LGBTQ people by planting its moralistic values into education (e.g. RE lessons) to hinder children from developing their own open stance towards sexual plurality.

The model integrates an Agent-Based and a System-Dynamics part. It builds on empirical data by the SINUS Institute (Calmbach et al. 2016), which uses a mixed-methods approach to describe the segmentation of German youth and to characterise the resulting seven *milieus* closely. First, a quantitative survey was carried out to find and roughly describe the milieus, and in a second step, members of each milieu were interviewed to get a detailed "anecdotally representative" picture of their experience realms.

Simulation results suggest a strong influence of society on how open or closed teenagers become towards sexual plurality. The openness of civil society likely depends on various factors such as the existence and perception of queer role models or policies regarding LGBTQ people (e.g., same-sex marriage). If civil society has a dedicated position regarding queer people, the resulting dynamics among adolescents are relatively resilient towards external pressure by government education, academic theology or institutional church. In general, the influence of the latter two factors seems lower than assumed by LGBTQ activists, who accuse the church of making adolescents closed-minded. Likewise, according to the simulation model, a progressive government education agenda mainly impacts those adolescents who grow open-minded anyway, contradicting Christian Conservatives who consider guidance by government education as a source of excessive openness. As a consequence of both mechanisms, an education agenda of the state holds more potential to induce closeness than openness, while vice versa, an open position of the institutional church and academic theology would be more influential than a closed one. This finding is likely to hold for younger children and adults, too. Overall, the model highlights that simply changing an influence of children's development process is not (necessarily) fit to alter that process as the ones changing the influence want. Complex interactions between actors in the modelled system lead to unpredictable emergent results. Put differently, young citizens perceive and weigh different influences differently and form their own opinion, thereby guaranteeing the persistence of a robust civil society as long as they grow up in one.

The stance towards LGBTQ people developed by members of one generation in adolescence might persist during adulthood. In other words, the value development of parents, teachers and other mentors indirectly influences the value development of their children, pupils and mentees. Thus, an extension of the original model (not part of this thesis, currently under review for *Simulieren und Entscheiden* vol. 2) with Johannes Marx (University of Bamberg) covers multiple generations by explicating feedback loops that endogenise the value of civil society. Furthermore, the extension widens the scope as it tackles not only stance towards queerness but value development in general (cf. Figure 1.2). Therefore, the SINUS data is revisited to ensure applicability of the mechanisms to broader general settings and theories of value development also feed into model calibration.

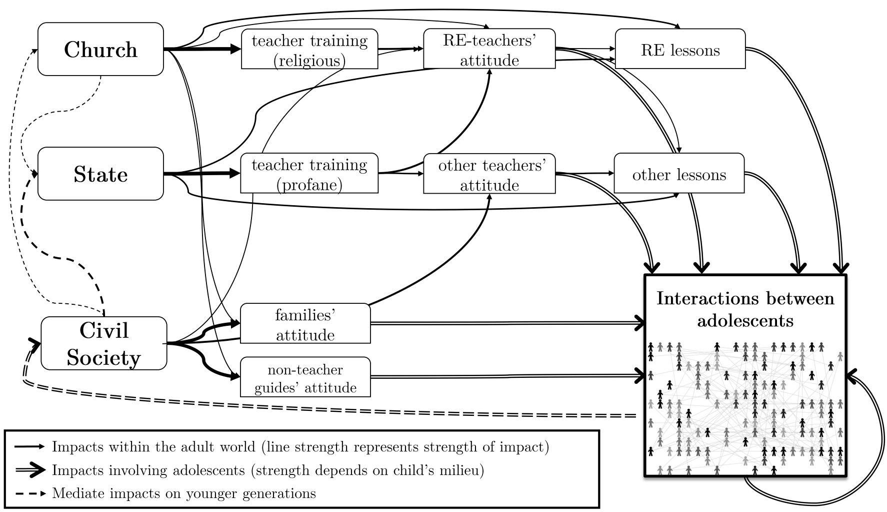

Figure 1.2: Systemic influences in the extended inter-generational model

The thesis paper and its extension constitute an example of the extension of an existing model. Since the domains were closely related, the need and sources for additional validation were as immanent as how the extension would work on the design and implementation level.

1.7 Potential Pitfalls: Spurious Similarities

Arguments that derive structural similarity from similar simulation output but presuppose this similarity in the construction and calibration of the respective models become circular. Yet, such circularity may not always be as obvious to readers (or even modellers themselves) in a specific case because working with a model is typically an iterated process: That design (including calibration), implementation and analysis become intertwined constitutes a strength of ABMs as research instruments for complex systems. However, to understand the role and potential problems arising in each task more clearly, this section disentangles them. Detailed and repeated reflection on these pitfalls will invoke modellers' caution. Consequently, they can apply their experience with validation tasks to carefully argue the model to model inferences that underlie structure transfers as explained in Section 1.4.3.

1.7.1 Spurious Similarities in Model Design

In conceptualising structural similarity in model design, one must be cautious only to include actual similarities. Proclaiming similarity that a theoretical or empirical description of the respective situations does not warrant is a form of the "Fallacy of Misplaced Concreteness" (Whitehead 1925, p 52): The similarity relation between model structures per se constitutes only an abstract characterisation and is no proof for the relationship to exist in the real world. Namely, the story of one or even both application cases might not fit the model structure.

Thus, to develop a model for application to two related cases, it is essential to check back regularly and calibrate it for each case. Sometimes, the new application case may even contradict the proposed structural parallels.[23] Consequently, without close consideration of both application cases, instead of hitting two birds with one stone, one will put much effort into throwing a stone (i.e. developing a model) that ends up hitting neither bird.

[23] For example, the preferential attachment network has received much attention because it does not only produce convenient network features but also represents some real-life communication networks very well (Barabasi & Albert 1999). Nevertheless, some models also apply it to communication structures that fail to exhibit a Preferential Attachment structure or mistake directed for undirected links.

Likewise, adjusting an existing model structure or meta-structure to a new application case, specific features of this case require incredibly close attention. Making a few changes to the original structure as possible may seem like good practice and in line with the KISS principle.[24] However, the existing parallel features may often not be the simplest way of modelling the new target system if modelling it in isolation. In these cases, modellers must carefully weigh the benefit of gaining insights about structural similarity against the additional effort needed for computing, analysing and communicating a model that is less straightforward than it could be if developed without the structural similarity in mind.

1.7.2 Spurious Similarities in Model Implementation

Technical implementation will be unproblematic when faithful to a model design that only includes structural similarities warranted for (or at least not contradicted) by theoretical or empirical observation. In this case, a transfer of bugs or incorrect hard-coded settings from one model implementation to another poses the gravest problem. If the bug or setting is of little consequence in the original model, it may have been overlooked but potentially concerns a more central part of the new one. Furthermore, a modeller may have forgotten how the original model worked and where it may still need refinement if a long time passes until they use the code for the new case or misunderstand someone else's code. Good coding practice - extensive testing and sufficient documentation - effectively prevents such transfer of bugs. The prospect of potential future reuse should motivate modellers to adhere to this good practice.

However, there may be the temptation to deviate from the model concept and reuse (parts of) an existing model for the sake of technological convenience. This either yields a model not depicting what one intends to depict or prompts ad-hoc modifications. The best-case consequence is a messy implementation that will require additional work to communicate. The worst-case scenario is an internally invalid implementation, i.e., a model that does not do as intended. If neither the modeller nor the readers spot that internal

[24] That relying on simplicity alone is not ideal for modern ABM has been acknowledged by modellers (Edmonds & Moss 2005; Terano 2008).

invalidity - e.g. because the reasons rest in code details - they may perceive material structural similarities that boil down to bad coding.

1.7.3 Spurious (Ignorance of) Similarities in Model Analysis

Even carefully designed models that entail spurious similarities neither in their concept nor their implementation may analysing simulation results may yield these spurious similarities in an unfortunate analysis or interpretation and presentation. This can come in two flavours: Firstly, one may treat aspects in the model alike that exhibit parallels at the model level but differ in what these aspects mean. For example, if an input or output straightforwardly represents a single factor in one model but is designed as a proxy for the other model, one must not treat them alike in the analysis. Secondly, the analysis may proclaim further-reaching parallels than the model design indeed features, talk about close parallels in sub-structures when there is only a common meta-structure or vice-versa.

The contrary of overstating similarities - their ignorance - in model outcome analysis poses a problem, too. Whenever parallels between models result from a deliberate choice in parallel model design or implementation, one must make this explicit. As a corollary, the corresponding design choices require explanation and justification, i.e., a dedicated discussion of the nature and extent of modelled structural similarity. Furthermore, only their explication allows readers to scrutinise the parallels.

An analysis or interpretation proclaims similarities that the model does not warrant or ignores similarities that originate in design or implementation choices may have two causes: A deliberate attempt to deceive readers and a lack of care. As an example of the more general phenomenon of unfaithful science, counteracting the first cause requires training modellers in the ethics of science and changing scientific institutions to disincentivise such practices. In order to detect them, reviewers would need to inspect the model implementations and check whether they are indeed (not) similar to each other. This act would also allow identifying a lack of care. To facilitate a thorough review and avoid overlooking design or technical aspects during analysis, modellers themselves should try to make their simulation models publicly available independent of the papers, as is already standard practice for most empirical data. This separation of modelling and analysis will help see whether the latter fits the former - not only in terms of structural similarity.

Moreover, the similarity resulting from parallels in two models per se is merely equivalent to an objectively possible how-possibly explanation (Grüne-Yanoff & Verreault-Julien 2021) of system behaviour in the two real-world situations being due to structural similarity. Hence, the parallels in model structure ask for validation as not conventionally incompatible with the face-level differences that lead us to perceive the two situations apart in general. To argue for the empirical possibility of the similarity moreover requires making a specific case why the proposed similarities in input, process and output are consistent with empirical data.

1.8 Conclusion

Transferring the structure of an ABM from one real-world application to another happens frequently and aids the investigation of the complex systems that the ABMs represent. One can understand the structure transfer as a story adaptation to the new application case. There are three ideal forms of this transfer: (I) employment of an identical structure to multiple cases, (II) extension or alteration of an existing structure in light of a new case, and (III) derivation of specific structures from a common meta-structure. Nevertheless, like many other modelling and general scientific activity, model structure transfer may be less clean in real life. Hence, the three types overlap and become intertwined, or a single model employs multiple structure transfers at once. Moreover, many modellers will not recognise the transfer explicitly. Yet, the reflection in this paper aided an understanding of the practice.

Model structure transfer bears the potential for an increase in efficiency for modellers and readers alike. Reusing the structure will typically also mean reusing its technical implementation; this can save much time and technical effort in coding, which is not by itself intellectually stimulating. However, there are also gains in model design when resorting to concepts that work as intended and in analysis because some or all model mechanisms are already understood. Consequently, a well-established structure also makes internal validation of the model more manageable, if not obsolete. Readers who already know the model structure - or bits of it - from other models have an easier time understanding the new one. Moreover, they may understand and evaluate it even more deeply because they can now focus on the structure in relation to the new application case.

Besides these efficiency considerations, a transfer of model structure from one application case to another can reveal the structural similarity between these cases and help to assess its extent quantitatively and qualitatively. Like the development of an ABM alone can aid the forming a clearer picture of the modelled situation, the transfer by itself can explicate a structural similarity also in the real world. Moreover, if there is structural similarity, insights gained from the ABMs but also an independent study of one of the modelled real-world situations may be applied to the respective other situation. Thus, ABM structure transfer is no mere auxiliary to modelling but constitutes an independent scientific endeavour. However, such endeavour may also fail or mislead because an identified structural similarity between two modelled situations does not exist.

Therefore, modellers must be cautious in transferring model structure to a different story. First of all, a structural similarity in models does not warrant structural similarity in the real world, but this similarity must be accounted for by thorough validation of both model stories and structures in their respective application cases. Sometimes, an attempt to transfer a structure will fail because the mechanisms differ in reality, and the simulation results in the new case are implausible. Then, one should not try to tweak the model ad-hoc but acknowledge (and possibly communicate) why the transfer did not work to develop a different structure. A failed transfer is an experience worth embracing, too. Specifically for Agent-Based Modelling, it will not always be desirable or necessary to transfer a model structure as a whole. Often, using an existing sub-procedure or extending an existing ABM will yield benefits in efficiency and facilitate the discovery of structural similarity in details of seemingly different larger real-world processes. Thus, conceptualising and implementing ABMs in a modular fashion that embodies multiple smaller templates is desirable. With these considerations in mind, the transfer of model structure to a different story context can be a technique that further enriches Agent-Based Modelling.

This paper has used ABMs as an example to show how one can investigate a structural similarity between two systems. Nevertheless, its central arguments apply to any method that aims to study complex systems, be it a theoretical approach, other modelling techniques or quantitative or qualitative research designs; and they hold true beyond the academic domain to complexity practitioners in government bodies, companies, or NGOs. Who exploits a presumed structural similarity of two systems should also be prepared to explicate and explain what constitutes this similarity and to study how far it reaches. Moreover, such exploitation of structural similarity extends to non-complexity perspectives on society, too. Therefore, finding insights about structural similarity can further enrich Agent-Based Modelling as a method, Political Science when it applies this method and Political Theory in its capacity to link different research programs or inspire new ones within and beyond Political Science.

References

Ahrweiler, P., Schilperoord, M., Pyka, A. & Gilbert, N. (2015). Modelling Research Policy: Ex-Ante Evaluation of Complex Policy Instruments. *Journal of Artificial Societies and Social Simulation*, *18*(4). doi:10.18564/jasss.2927 URL `http://dx.doi.org/10.18564/jasss.2927`

Asgharpourmasouleh, A., Fattahzadeh, M., Mayerhoffer, D. & Lorenz, J. (2019). On the Fate of Protests: Dynamics of Social Activation and Topic Selection Online and in the Streets. In *Computational Social Sciences*, (pp. 141–164). Springer International Publishing

Autor, D., Dorn, D., Katz, L. F., Patterson, C. & Von Reenen, J. (2019). The Fall of the Labor Share and the Rise of Superstar Firms. *Quarterly Journal of Economics*, *forthcoming*

Axelrod, R. (2000). *Harnessing complexity : organizational implications of a scientific frontier*. New York: Basic Books (reprint 2014)

Axtell, R. L. (2001). Zipf distribution of US firm sizes. *Science*, *293*(5536), 1818–1820

Badham, J., Jansen, C., Shardlow, N. & French, T. (2017). Calibrating with Multiple Criteria: A Demonstration of Dominance. *Journal of Artificial Societies and Social Simulation*, *20*(2). doi:10.18564/jasss.3212
URL `http://dx.doi.org/10.18564/jasss.3212`

Barabasi, A.-L. & Albert, R. (1999). Emergence of Scaling in Random Networks. *Science*, *286*(5439), 509–512. doi:10.1126/science.286.5439.509
URL `http://dx.doi.org/10.1126/science.286.5439.509`

Bavel, J. V. & Grow, A. (2016). Introduction: Agent-Based Modelling as a Tool to Advance Evolutionary Population Theory. In *Agent-Based Modelling in Population Studies*, (pp. 3–27). Springer International Publishing

Bechtel, W. (1985). Realism, Instrumentalism, and the Intentional Stance. *Cognitive Science*, *9*(4), 473–497

Buckley, W. (1967). *Sociology and modern systems theory.* Englewood Cliffs, N.J: Prentice-Hall

Buckley, W. (1998). *Society– a complex adaptive system : essays in social theory.* Australia: Gordon and Breach

Calder, M., Craig, C., Culley, D., de Cani, R., Donnelly, C. A., Douglas, R., Edmonds, B., Gascoigne, J., Gilbert, N., Hargrove, C., Hinds, D., Lane, D. C., Mitchell, D., Pavey, G., Robertson, D., Rosewell, B., Sherwin, S., Walport, M. & Wilson, A. (2018). Computational modelling for decision-making: where, why, what, who and how. *Royal Society Open Science*, *5*(6), 172096. doi:10.1098/rsos.172096
URL `http://dx.doi.org/10.1098/rsos.172096`

Calmbach, M., Borgstedt, S., Borchard, I., Thomas, P. M. & Flaig, B. B. (2016). *Wie ticken Jugendliche 2016?* Springer Fachmedien Wiesbaden

Cartwright, N. (2010). *Models: Parables v Fables*, (pp. 19–31). Dordrecht: Springer Netherlands

Checkland, P. (2000). Soft Systems Methodology: A Thirty Year Retrospective. *Systems Research and Behavioral Science*, *17*, 11–58

Checkland, P. & Poulter, J. (2010). Soft Systems Methodology. In M. Reynolds & S. Holwell (Eds.), *Systems Approaches to Managing Change: A Practical Guide*, (pp. 191–242). Springer

Cioppa, T. M., Lucas, T. W. & Sanchez, S. (2004). Military Applications of Agent-Based Simulations. In *Proceedings of the 2004 Winter Simulation Conference, 2004.* IEEE. doi:10.1109/wsc.2004.1371314
URL `http://dx.doi.org/10.1109/wsc.2004.1371314`

Coleman, J. (1990). *Foundations of social theory*. Cambridge, Mass: Belknap Press of Harvard University Press

Conte, R. & Gilbert, N. (1995). Introduction: computer simulation for social theory. In N. Gilbert & R. Conte (Eds.), *Artificial Societies: The Computer Simulation of Social Life*, (pp. 1–15). UCL Press, London

Damascelli, A. (2004). Probing the Electronic Structure of Complex Systems by ARPES. *Physica Scripta*, *T109*, 61. doi:10.1238/physica.topical.109a00061
URL http://dx.doi.org/10.1238/physica.topical.109a00061

de Marchi, S. & Page, S. E. (2014). Agent-Based Models. *Annual Review of Political Science*, *17*(1), 1–20. doi:10.1146/annurev-polisci-080812-191558
URL http://dx.doi.org/10.1146/annurev-polisci-080812-191558

Deckert, A. & Klein, R. (2010). Agentenbasierte Simulation zur Analyse und Lösung betriebswirtschaftlicher Entscheidungsprobleme. *Journal für Betriebswirtschaft*, *60*(2), 89–125. doi:10.1007/s11301-010-0058-6
URL http://dx.doi.org/10.1007/s11301-010-0058-6

Deissenroth, M., Klein, M., Nienhaus, K. & Reeg, M. (2017). Assessing the Plurality of Actors and Policy Interactions: Agent-Based Modelling of Renewable Energy Market Integration. *Complexity*, *2017*, 1–24. doi:10.1155/2017/7494313
URL http://dx.doi.org/10.1155/2017/7494313

Dennett, D. C. (2017). *Brainstorms: Philosophical Essays on Mind and Psychology*. MIT Press, 8 edn.

Dequech, D. (2007). Neoclassical, mainstream, orthodox, and heterodox economics. *Journal of Post Keynesian Economics*, *30*(2), 279–302. doi:10.2753/pke0160-3477300207
URL http://dx.doi.org/10.2753/pke0160-3477300207

Dijkema, G. P. J., Lukszo, Z. & Weijnen, M. P. C. (2013). Introduction. In *Agent-Based Modelling of Socio-Technical Systems*, (pp. 1–8). Springer Netherlands

Dosi, G., Pereira, M. C. & Virgillito, M. E. (2017). The footprint of evolutionary processes of learning and selection upon the statistical properties of industrial dynamics. *Industrial and Corporate Change*, *26*(2), 187–210

Dubbelboer, J., Nikolic, I., Jenkins, K. & Hall, J. (2017). An Agent-Based Model of Flood Risk and Insurance. *Journal of Artificial Societies and Social Simulation*, *20*(1)

Duffy, F., Klosek, K. C., Nardin, L. G. & Wagner, G. (2019). Rebel Group Protection Rackets: Simulating the Effects of Economic Support on Civil War Violence. In *Computational Social Sciences*, (pp. 225–251). Springer International Publishing

Edmonds, B. & Moss, S. (2005). From KISS to KIDS – An 'Anti-simplistic' Modelling Approach. In P. Davidsson, B. Logan & K. Takadama (Eds.), *Multi-Agent and Multi-Agent-Based Simulation*, (pp. 130–144). Berlin, Heidelberg: Springer Berlin Heidelberg

Elster, J. (1989). *Nuts and Bolts for the Social Sciences*. Cambridge University Press

Epstein, J. (2006). *Generative Social Science : Studies in Agent-Based Computational Modeling*. Place of publication not identified: Princeton University Press

Epstein, J. M. (1999). Agent-based computational models and generative social science. *Complexity*, *4*(5), 41–60

Epstein, J. M. & Axtell, R. L. (1996). *Growing Artificial Societies*. MIT Press Ltd

Erdős, P. & Rényi, A. (1960). On the evolution of random graphs. *Publ. Math. Inst. Hung. Acad. Sci*, *5*(1), 17–60

Fagiolo, G., Guerini, M., Lamperti, F., Moneta, A. & Roventini, A. (2019). Validation of Agent-Based Models in Economics and Finance. In C. Beisbart & N. J. Saam (Eds.), *Computer Simulation Validation: Fundamental Concepts, Methodological Frameworks, and Philosophical Perspectives*, (pp. 763–787). Cham: Springer International Publishing

Farmer, J. D. (2016). We Have an Increasing Need to Model Purselves. In S. Thurner (Ed.), *Exploring Complexity*, (pp. 15–16). World Scientific

Flache, A. & Macy, M. (2011). Social Dynamics from the Bottom Up. In P. Bearman & P. Hedström (Eds.), *The Oxford Handbook of Analytical Sociology*. Oxford University Press. doi:10.1093/oxfordhb/9780199215362.013.11
URL `http://dx.doi.org/10.1093/oxfordhb/9780199215362.013.11`

Fowler, J. H. & Smirnov, O. (2005). Dynamic Parties and Social Turnout: An Agent-Based Model. *American Journal of Sociology*, *110*(4), 1070–1094. doi:10.1086/426554
URL `http://dx.doi.org/10.1086/426554`

Franklin, S. & Graesser, A. (1997). Is It an agent, or just a program?: A taxonomy for autonomous agents. In *Intelligent Agents III Agent Theories, Architectures, and Languages*, (pp. 21–35). Springer Berlin Heidelberg. doi: 10.1007/bfb0013570
URL `http://dx.doi.org/10.1007/bfb0013570`

Gabaix, X. (2011). The Granular Origins of Aggregate Fluctuations. *Econometrica*, *79*(3), 733–772

Gaus, G. (2013). On Theorizing about Public Reason. *European Journal of Analytic Philosophy*, *9*(1), 64–85

Gaus, G. (2017). Self-organizing moral systems: Beyond social contract theory. *Politics, Philosophy and Economics*, *17*(2), 119–147

Gaus, G. (2021). *The Open Society and Its Complexities*. Oxford University Press

Gerrits, L. (2012). *Punching clouds : an introduction to the complexity of public decision-making*. Litchfield Park, AZ: Emergent Publications

Gibbard, A. & Varian, H. R. (1978). Economic models. *The Journal of Philosophy*, *75*(11), 664–677

Giere, R. (1988). *Explaining science : a cognitive approach*. Chicago: University of Chicago Press

Gilbert, N. (2019). *Agent-Based Models*. SAGE Publishing

Gilbert, N., Ahrweiler, P., Barbrook-Johnson, P., Narasimhan, K. P. & Wilkinson, H. (2018). Computational Modelling of Public Policy: Reflections on Practice. *Journal of Artificial Societies and Social Simulation*, *21*(1). doi:10.18564/jasss.3669
URL `http://dx.doi.org/10.18564/jasss.3669`

Gilbert, N. & Troitzsch, K. G. (2005). *Simulation for the Social Scientist*. Open University Press

Gräbner, C. (2018). How to relate models to reality? An epistemological framework for the validation and verification of computational models. *Journal of Artificial Societies and Social Simulation*, *21*(3)

Grüne-Yanoff, T. & Verreault-Julien, P. (2021). How-possibly explanations in economics: anything goes? *Journal of Economic Methodology*, *28*(1), 114–123

Grüne-Yanoff, T. (2009). Learning from minimal economic models. *Erkenntnis*, *70*(1), 81–99

Hausman, D. M. (1992). *Inexact Separate Science Econo.* Cambridge University Press

Hedström, P. & Swedberg, R. (1998). Social mechanisms: An introductory essay. In *Social Mechanisms*, (pp. 1–31). Cambridge University Press. doi:10.1017/cbo9780511663901.001
URL `http://dx.doi.org/10.1017/cbo9780511663901.001`

Hedström, P. & Ylikoski, P. (2010). Causal Mechanisms in the Social Sciences. *Annual Review of Sociology*, *36*(1), 49–67. doi:10.1146/annurev.soc.012809.102632
URL `http://dx.doi.org/10.1146/annurev.soc.012809.102632`

Hedstrom, P. (2005). *Dissecting the Social.* Cambridge University Press

Hegselmann, R., & Krause, U. (2015). Opinion dynamics under the influence of radical groups, charismatic leaders, and other constant signals: A simple unifying model. *Networks & Heterogeneous Media*, *10*(3), 477–509. doi:10.3934/nhm.2015.10.477
URL `http://dx.doi.org/10.3934/nhm.2015.10.477`

Hegselmann, R. & Flache, A. (1998). Understanding Complex Social Dynamics: A Plea For Cellular Automata Based Modelling. *Journal of Artificial Societies and Social Simulation*, *1*(3)

Hegselmann, R. & Krause, U. (2002). Opinion dynamics and bounded confidence models, analysis, and simulation. *Journal of artificial societies and social simulation*, *5*(3)

Hegselmann, R. & Will, O. (2010). Modelling Hume's Moral and Political Theory. The Design of Hume 2.0. In *Norms and Values*, (pp. 205–233). Nomos. doi:10.5771/9783845224350-205
URL `http://dx.doi.org/10.5771/9783845224350-205`

Holland, J. (1998). *Emergence : from chaos to order*. Reading, Mass: Addison-Wesley

Houkes, W. & Zwart, S. D. (2019). Transfer and templates in scientific modelling. *Studies in History and Philosophy of Science Part A*, *77*, 93–100. doi:10.1016/j.shpsa.2017.11.003
URL `http://dx.doi.org/10.1016/j.shpsa.2017.11.003`

Humphreys, P. (2004). *Extending Ourselves: Computational Science, Empiricism, and Scientific Method.* Oxford University Press

Humphreys, P. (2019). Knowledge transfer across scientific disciplines. *Studies in History and Philosophy of Science Part A*, *77*, 112–119. doi:10.1016/j.shpsa.2017.11.001
URL `http://dx.doi.org/10.1016/j.shpsa.2017.11.001`

Johnson, J. (2020). Models-As-Fables: An Alternative to the Standard Rationale for Using Formal Models in Political Science. *Perspectives on Politics*, *19*(3), 874–889. doi:10.1017/s1537592720003473
URL `http://dx.doi.org/10.1017/s1537592720003473`

Johnson, P. (2015). Agent-Based Models as "Interested Amateurs". *Land*, *4*(2), 281–299. doi:10.3390/land4020281
URL `http://dx.doi.org/10.3390/land4020281`

Kirman, A. (1993). Ants, Rationality, and Recruitment. *The Quarterly Journal of Economics*, *108*(1), 137–156. doi:10.2307/2118498
URL `http://dx.doi.org/10.2307/2118498`

Klein, D. & Marx, J. (2017). Wenn Du gehst, geh ich auch! Die Rolle von Informationskaskaden bei der Entstehung von Massenbewegungen. *Politische Vierteljahresschrift*, *58*(4), 560–592. doi:10.5771/0032-3470-2017-4-560
URL `http://dx.doi.org/10.5771/0032-3470-2017-4-560`

Klein, D., Marx, J. & Fischbach, K. (2018). Agent-Based Modeling in Social Science, History, and Philosophy. An Introduction. *Historical Social Research / Historische Sozialforschung*, *43*, 7–27. doi:10.12759/HSR.43.2018.1.7-27
URL `http://dx.doi.org/10.12759/HSR.43.2018.1.7-27`

Knuuttila, T. (2011). Modelling and representing: An artefactual approach to model-based representation. *Studies in History and Philosophy of Science Part A*, *42*(2), 262–271. doi:10.1016/j.shpsa.2010.11.034
URL `http://dx.doi.org/10.1016/j.shpsa.2010.11.034`

Knuuttila, T. & Loettgers, A. (2016). Model templates within and between disciplines: from magnets to gases – and socio-economic systems. *European Journal for Philosophy of Science*, *6*(3), 377–400. doi:10.1007/s13194-016-0145-1
URL `http://dx.doi.org/10.1007/s13194-016-0145-1`

Knuuttila, T. & Morgan, M. S. (2019). Deidealization: No Easy Reversals. *Philosophy of Science*, *86*(4), 641–661. doi:10.1086/704975
URL `http://dx.doi.org/10.1086/704975`

Kollman, K. & Page, S. E. (2006). Chapter 29 Computational Methods and Models of Politics. In *Handbook of Computational Economics*, (pp. 1433–1463). Elsevier

Koopmans, T. C. (1957). *Three Essays on the State of Economic Science*. McGraw-Hill

Ladyman, J., Lambert, J. & Wiesner, K. (2012). What is a complex system? *European Journal for Philosophy of Science*, *3*(1), 33–67. doi:10.1007/s13194-012-0056-8
URL http://dx.doi.org/10.1007/s13194-012-0056-8

Laver, M. (2012). *Party competition : an agent-based model*. Princeton, N.J. Oxford: Princeton University Press

Liu, Y. & Ye, H. (2012). The dynamic study on firm's environmental behavior and influencing factors: an adaptive agent-based modeling approach. *Journal of Cleaner Production*, *37*, 278–287. doi:10.1016/j.jclepro.2012.07.025
URL http://dx.doi.org/10.1016/j.jclepro.2012.07.025

Love-Koh, J. (2019). How Useful Are Early Economic Models? Comment on "Problems and Promises of Health Technologies: The Role of Early Health Economic Modelling". *International Journal of Health Policy and Management*. doi:10.15171/ijhpm.2019.119
URL http://dx.doi.org/10.15171/ijhpm.2019.119

Luhmann, N. (1997). *Die Gesellschaft der Gesellschaft*. Frankfurt am Main: Suhrkamp

Macy, M. W. & Willer, R. (2002). From Factors to Actors: Computational Sociology and Agent-Based Modeling. *Annual Review of Sociology*, *28*(1), 143–166. doi:10.1146/annurev.soc.28.110601.141117
URL http://dx.doi.org/10.1146/annurev.soc.28.110601.141117

Malerba, F. & McKelvey, M. (2018). Knowledge-intensive innovative entrepreneurship integrating Schumpeter, evolutionary economics, and innovation systems. *Small Business Economics*, *54*(2), 503–522. doi: 10.1007/s11187-018-0060-2
URL http://dx.doi.org/10.1007/s11187-018-0060-2

Marks, P., Gerrits, L. & Marx, J. (2019). How to use fitness landscape models for the analysis of collective decision-making: a case of theory-transfer and its limitations. *Biology & Philosophy*, *34*(1). doi:10.1007/s10539-018-9669-4
URL http://dx.doi.org/10.1007/s10539-018-9669-4

Martens, W. (2000). Organisation und gesellschaftliche Teilsysteme. In *Theorien der Organisation*, (pp. 263–311). VS Verlag für Sozialwissenschaften

Mayerhoffer, D., Schulz, J. & Scheller, S. (forthcoming). Multidimensionale Krisendiskurse in komplexen Gesellschaften. In M. Ott & M. Mühlnikel (Eds.), *Wege aus der Krise*. tba

Mayerhoffer, D. M. (2018). Raising Children to Be (In-)Tolerant. Influence of Church, Education, and Society on Adolescents' Stance towards Queer People in Germany. *Historical Social Research*, *43*, 144–167. doi:10.12759/HSR.43.2018.1.144-167
URL `http://dx.doi.org/10.12759/HSR.43.2018.1.144-167`

McConnell, A. R. (2010). The Multiple Self-Aspects Framework: Self-Concept Representation and Its Implications. *Personality and Social Psychology Review*, *15*(1), 3–27. doi:10.1177/1088868310371101
URL `http://dx.doi.org/10.1177/1088868310371101`

Meisser, L. (2016). The Code is the Model. *International Journal of Microsimulation*, *10*(3), 184–201. doi:10.34196/ijm.00169
URL `http://dx.doi.org/10.34196/ijm.00169`

Mäki, U. (2005). Models are experiments, experiments are models. *Journal of Economic Methodology*, *12*(2), 303–315. doi:10.1080/13501780500086255
URL `http://dx.doi.org/10.1080/13501780500086255`

Mäki, U. (2009). MISSing the World. Models as Isolations and Credible Surrogate Systems. *Erkenntnis*, *70*(1), 29–43. doi:10.1007/s10670-008-9135-9
URL `http://dx.doi.org/10.1007/s10670-008-9135-9`

Morgan, M. S. (2001). Models, stories and the economic world. *Journal of Economic Methodology*, *8*(3), 361–384. doi:10.1080/13501780110078972
URL `http://dx.doi.org/10.1080/13501780110078972`

Morrison, M. (2015). *Reconstructing Reality: Models, Mathematics, and Simulations*. Oxford University Press

Morrison, M. & Morgan, M. S. (1999). Models as mediating instruments. In *Models as Mediators*, (pp. 10–37). Cambridge University Press. doi:10.1017/cbo9780511660108.003
URL `http://dx.doi.org/10.1017/cbo9780511660108.003`

Moya, I., Chica, M., Sáez-Lozano, J. L. & Cordón, Ó. (2021). Simulating the influence of terror management strategies on the voter ideological distance using agent-based modeling. *Telematics and Informatics*, *63*, 101656. doi:10.1016/j.tele.2021.101656
URL `http://dx.doi.org/10.1016/j.tele.2021.101656`

Parnas, D. L., Clements, P. C. & Weiss, D. M. (1984). The Modular Structure of Complex Systems. *IEEE Transactions on software Engineering*, *3*, 259–266

Plümper, T. & Martin, C. W. (2008). Multi-party competition: A computational model with abstention and memory. *Electoral Studies*, *27*(3), 424–441

Pluchino, A., Rapisarda, A. & Garofalo, C. (2010). The Peter principle revisited: A computational study. *Physica A: Statistical Mechanics and its Applications*, *389*(3), 467–472. doi:10.1016/j.physa.2009.09.045
URL http://dx.doi.org/10.1016/j.physa.2009.09.045

Reutlinger, A., Hangleiter, D. & Hartmann, S. (2018). Understanding (with) Toy Models. *The British Journal for the Philosophy of Science*, *69*(4), 1069–1099. doi:10.1093/bjps/axx005
URL http://dx.doi.org/10.1093/bjps/axx005

Rubinstein, A. (2006). Dilemmas of an Economic Theorist. *Econometrica*, *74*(4), 865–883

Russell, S. & Norvig, P. (2021). *Artificial Intelligence: A Modern Approach, Global Edition*. Pearson ITP

Scalco, A., Macdiarmid, J. I., Craig, T., Whybrow, S. & Horgan, G. W. (2019). An Agent-Based Model to Simulate Meat Consumption Behaviour of Consumers in Britain. *Journal of Artificial Societies and Social Simulation*, *22*(4), 8. doi:10.18564/jasss.4134
URL http://dx.doi.org/10.18564/jasss.4134

Scheller, S. (2019). The Strategic Use of Fear Appeals in Political Communication. *Political Communication*, *36*(4), 586–608. doi:10.1080/10584609.2019.1631918
URL http://dx.doi.org/10.1080/10584609.2019.1631918

Schelling, T. (1978). *Micromotives and macrobehavior*. New York: Norton

Schelling, T. C. (1969). Models of Segregation. *Rand Memoranda*, (RM-6014-RC)

Schelling, T. C. (1971). Dynamic models of segregation†. *The Journal of Mathematical Sociology*, *1*(2), 143–186. doi:10.1080/0022250x.1971.9989794
URL http://dx.doi.org/10.1080/0022250x.1971.9989794

Schimank, U. (1997). Kommentar: Zur Verknüpfung von Gesellschafts- und Organisationstheorie. In *Theorien der Organisation*, (pp. 312–314). Verlag für Sozialwissenschaften

Schimank, U. (1999). Drei Wünsche zur soziologischen Theorie. *Soziale Welt*, *50*(4), 415–421

Schimank, U. (2005). Funktionale Differenzierung und Systemintegration der modernen Gesellschaft. In *Differenzierung und Integration der modernen Gesellschaft*, (pp. 185–197). Verlag für Sozialwissenschaften

Schmolke, A., Thorbek, P., DeAngelis, D. L. & Grimm, V. (2010). Ecological models supporting environmental decision making: a strategy for the future. *Trends in Ecology & Evolution*, *25*(8), 479–486. doi:10.1016/j.tree.2010.05.001
URL `http://dx.doi.org/10.1016/j.tree.2010.05.001`

Schulz, J. & Mayerhoffer, D. M. (2021). Equal Chances, Unequal Outcomes? Network-Based Evolutionary lLearning and the Industrial Dynamics of Superstar Firms. *Journal of Business Economics*, *91*(9), 1357–1385. doi:10.1007/s11573-021-01047-8
URL `http://dx.doi.org/10.1007/s11573-021-01047-8`

Simon, H. A. (1990). Bounded Rationality. In J. Eatwell, M. Milgate & P. Newman (Eds.), *Utility and Probability*, (pp. 15–18). London: Palgrave Macmillan UK

Squazzoni, F. (2012). *Agent-Based Computational Sociology*. WILEY

Sterman, J. D. (1994). Learning In and About Complex Systems. *System Dynamics Review*, *10*(2-3), 291–330

Suarez, M. (2009). *Fictions in science : philosophical essays on modeling and idealization*. New York: Routledge

Sugden, R. (2000). Credible worlds: the status of theoretical models in economics. *Journal of economic methodology*, *7*(1), 1–31

Sugden, R. (2009). Credible worlds, capacities and mechanisms. *Erkenntnis*, *70*(1), 3–27

Suppes, P. (1960). A comparison of the meaning and uses of models in mathematics and the empirical sciences. *Synthese*, *12*(2-3), 287–301. doi:10.1007/bf00485107
URL `http://dx.doi.org/10.1007/bf00485107`

Terano, T. (2008). Beyond the KISS Principle for Agent-Based Social Simulation. *Journal of Socio-Informatics*, (pp. 175–187)

Weber, M. (1984). *Gesamtausgabe*. Tübingen: J.C.B. Mohr

Weisberg, M. (2007). Who is a Modeler? *The British Journal for the Philosophy of Science*, *58*(2), 207–233. doi:10.1093/bjps/axm011
URL `http://dx.doi.org/10.1093/bjps/axm011`

Whitehead, A. N. (1925). *Science and the Modern World*. Free Press. Reprinted in 1997

Windrum, P., Fagiolo, G. & Moneta, A. (2007). Empirical validation of agent-based models: Alternatives and prospects. *Journal of Artificial Societies and Social Simulation*, *10*(2)

Wooldridge, M. J. & Jennings, N. R. (1995). Intelligent Agents: Theory and Practice. *The Knowledge Engineering Review*, *10*(2), 115–152

Yang, L. & Gilbert, N. (2008). Getting away from Numbers: Using QUalitative Observation for AGent-Based Modelling. *Advances in Complex Systems*, *11*(02), 175–185. doi:10.1142/s0219525908001556
URL `http://dx.doi.org/10.1142/s0219525908001556`

Zollman, K. J. S. (2005). Talking to Neighbors: The Evolution of Regional Meaning. *Philosophy of Science*, *72*(1), 69–85. doi:10.1086/428390
URL `http://dx.doi.org/10.1086/428390`

2

Equal Chances, Unequal Outcomes? Network-Based Evolutionary Learning and the Industrial Dynamics of Superstar Firms

Joint work with J. Schulz.

Schulz, J., Mayerhoffer, D.M. Equal chances, unequal outcomes? Network-based evolutionary learning and the industrial dynamics of superstar firms. *Journal of Business Economics* 91, 1357–1385 (2021). https://doi.org/10.1007/s11573-021-01047-8

The authors thank Giovanni Dosi and Marcello Pereira for sharing their code and explaining their rationale; for helpful comments on style and content (in alphabetical order) Anna Gebhard, Bettina Gregg, Torsten Heinrich, Dominik Klein, Johannes Marx, Alessandro Lucini Paioni, Roland Parr, Simon Scheller, Jürgen Sirsch, Moritz Schulz and Jan Weber as well as the participants of the WICK 2020 and EAEPE 2020 conferences. We are especially indebted to two anonymous reviewers and the editor Tim Weitzel for multiple insightful comments and suggestions to improve our paper. All remaining errors are our own, of course. This paper first circulated under the title "Innovation of Incumbents and Entrants in Localised Competition". We are immensely grateful to Tim Weitzel for pointing us to a more appropriate title.

Abstract

With the advent of platform economies and the increasing availability of online price comparisons, many empirical markets now select on relative rather than absolute performance. This feature might give rise to the 'winner takes all/most' phenomenon, where tiny initial productivity differences amount to large differences in market shares. We study the effect of heterogeneous initial productivities arising from locally segregated markets on aggregate outcomes, e.g., regarding revenue distributions. Several of those firm-level characteristics follow distributional regularities or 'scaling laws' (Brock 1999). Among the most prominent are Zipf's law describing the largest firms' extremely concentrated size distribution and the robustly fat-tailed nature of firm size growth rates, indicating a high frequency of extreme growth events. Dosi et al. (2017b) recently proposed a model of evolutionary learning that can simultaneously explain many of these regularities. We propose a parsimonious extension to their model to examine the effect for deviations in market structure from global competition, implicitly assumed in Dosi et al. (2017b). This extension makes it possible to disentangle the effects of two modes of competition: the global competition for sales and the localised competition for market power, giving rise to industry-specific entry productivity. We find that the empirically well-established combination of 'superstar firms' and Zipf tail is consistent only with a knife-edge scenario in the neighbourhood of most intensive local competition. Our model also contests the conventional wisdom derived from a general equilibrium setting that maximum competition leads to minimum concentration of revenue (Silvestre 1993). We find that most intensive local competition leads to the highest concentration, whilst the lowest concentration appears for a mild degree of (local) oligopoly. Paradoxically, a level playing field in initial conditions might induce extreme concentration in market outcomes.

JEL Codes C63 D21 D43 L11 L13 L14

Contents of this Paper

2.1 Introduction

Within an increasing number of markets, an individual firm‘s fate is no longer determined by absolute performance but by its performance relative to its competitors. Put differently, individual success in the market is a function of the now widespread availability of price comparisons on the internet (Akerman et al. 2021) and platform competition (Autor et al. 2020). In those ‘winner takes all/most’ markets, tiny differences in initial productivity can manifest themselves into large differences in market shares, typically leading to a high emergent concentration of market power. Somewhat surprisingly, the determinants of initial productivity at market entry have received little scholarly attention. We systematically explore the aggregate effects of heterogeneous initial conditions by exploiting a plausible notion of industry-specific productivity within locally segregated markets. Our approach builds on the intuition that comparisons of relative performance are seldom global and typically localised. For example, Uber and Alphabet not competing within the same submarket, even though their business strategies building on network effects and intangibles appear to be very similar. Our results suggest that market segmentation exhibits sizeable and counter-intuitive effects on the distribution of market shares, on firm growth and firm survival.

Empirically, these aforementioned firm-level characteristics follow distributional regularities or 'scaling laws' (Brock 1999), whose underlying mechanisms require expation. Dosi et al. (2017b) recently proposed a model of industrial dynamics that features evolutionary learning: Individual firms innovate and increase their productivity but compete for market shares according to a global selection mechanism based on productivity. This *evolutionary learning* mechanism combines cumulative learning with a 'winner takes all/most' market structure. Despite its bare-bones, partial equilibrium nature, the model is able to explain a surprising number of stylised facts in industrial dynamics, such as strongly heterogeneous size distributions, scaling between size growth rates and their variance as well as (persistent) heterogeneity in productivity. The model has been applied succesfully and essentially unchanged in a macroeconomic setting both for explanatory purposes and policy experiments in the 'Keynes meets Schumpeter' (K+S) modelling approach (Dosi et al. 2010, 2013, 2015, 2017a). Apart from the K+S approach, the distributional regularities, which even the partial model produces, have been identified to be of great macroeconomic relevance (Gabaix 2011; di Giovanni et al. 2011).

We propose a parsimonious extension to this model to examine the effect for deviations in market structure from global competition. Namely, we introduce a network structure of localised competition and innovation. This extension makes it possible to disentangle effects from two modes of competition: global competition for sales and localised competition for market power, giving rise to industry-specific productivity differences. Our contribution is thus twofold: Firstly, we test the benchmark model results' robustness for different market structures, as defined by local competition for market shares and localised entry, where the entry process' precise nature has recently been identified as the most important driver of aggregate outcomes within the model (Dosi et al. 2018). By this, we are able to constrain the range of possible competitive mechanisms in light of the empirical evidence in more detail. Secondly, we take a complementary approach to the macroeconomic implementations and examine even further the micro processes that different competition structures induce. These microeeconomic considerations have consequences for regulatory policy and implications even at the managerial level, in particular, for market entry timings.

Besides the cumulative idiosyncratic learning mechanism from our benchmark, for a non-complete network, our model also features a second process that distinguishes between firms' different productivity levels: When a new firm enters the model market, it acquires an industry-specific productivity level, modelled as the weighted average productivity of its direct competitors. This mechanism applies to a firm only once in its lifetime, namely at foundation/market entry. Nonetheless, it can crucially shape the entire life of a firm, since initial productivity determines whether an entrant can stabilise its position in the market or is quickly forced out of it again: We show that successful entrants typically join highly productive product markets. Hence, from a management perspective, our findings underline the importance of timing market entrance and thorough search prior to entry. Namely, our model can explain, why Schlichte et al. (2019) find the most successful firms to be fast followers in innovative markets rather than the original innovators themselves.

We find that the empirically well-established combination of 'superstar firms' and Zipf tails is consistent only with a knife-edge scenario in the neighbourhood of most intensive local competition. Moreover, our contests the conventional wisdom derived from a general equilibrium setting that maximum competition leads to minimum concentration of revenue (Silvestre 1993). Instead, we find that most intensive local competition leads to the highest concentration and the lowest concentration appears for a mild degree of (local) oligopoly. Relating to a different notion of competition, this finding might also be interpreted as evidence that 'winner takes all/most' markets are far from the ordoliberal ideal which considers "competition [to be] the most ingenious disempowerment instrument in history" (Böhm 1960, p. 22, author's translation). By contrast, it is precisely the ordoliberal demands for a 'level playing field' in combination with 'performance based competition' which lead to the highest concentration of revenue and hence power asymmetries within such markets that ordoliberals hope to avoid (Dold & Krieger 2019).

The remainder of this paper is organised as follows: We firstly discuss the stylised empirical facts that we intend to study as well as concepts and models on which we build (Section 2.2), followed by a detailed introduction of our model, based on Dosi et al. (2017b) (Section 2.3). Thereafter, we present the core simulation outcomes and explain their generating mechanisms (Section 2.4). Finally, we situate our findings in economic, policy and business discussions, drawing practical as well as normative implications, before closing with proposals for further research Section 4.4).

2.2 Models of Evolutionary Learning as a Representation of Empirical Findings

2.2.1 Stylised Facts in Industrial Dynamics

As a selection criterion for the parameter range that our proposed model spans, we use a set of stylised facts from traditional microeconometric literature and the industrial dynamics literature on distributional regularities in various firm-specific variables. The most prominent of these regularities is the finding of Zipf's law, originally based in linguistics (Zipf 1949), for the upper tail of firm size distributions. This implies that the size distributions of the largest firms are extremely concentrated, where the second-largest firm has only approximately one half of the size of the largest, the third-largest only a third and so on. Zipf's law in firm sizes appears to be a genuine and universal characteristic of market economies. A non-exhaustive list of studies on Zipf's findings include Axtell (2001) for the US, di Giovanni et al. (2011) for France, Pascoal et al. (2016) for Portugal, Okuyama et al. (1999) for Japan, Kang et al. (2011) for the Republic of Korea, Zhang et al. (2009) along with Heinrich & Dai (2016) for China, and Fujiwara et al. (2004) for several European countries. This empirical regularity not only constrains the set of possible generating mechanisms, but Zipf's law has also been linked to several important economic phenomena, such as the surge in CEO payments in recent decades (Gabaix & Landier 2008), the explanation of aggregate fluctuations from the micro-level together with increases in aggregate volatility (Gabaix 2011) and the welfare effects of barriers to entry and trade liberalisation (Di Giovanni & Levchenko 2013). This whole strand of macroeconomic literature takes Zipf's law as their starting point but does not examine possible conditions for which it emerges. Our findings on the determinants for Zipf's law might also provide insights on how to influence this wide range of phenomena, from CEO payments to aggregate fluctuations and international trade, which from a structural perspective this literature takes as given.

Another phenomenon of similar attributed economic relevance is the recent emergence of 'superstar firms', that operate in 'winner takes most/all' markets. They have experienced substantial and sustained increases in revenue over relatively short amounts of time (Autor et al. 2020). Anecdotal examples for this behavior are Alphabet and Uber. The rise of these firms has been proposed as an explanation for the recent decline in the labour share of national income (Autor et al. 2020), otherwise famously staying constant throughout the most part of recorded history of capitalist economies (Kaldor 1961) and the rise of wage inequality (Gabaix & Landier 2008).

Growth in various measures of size such as gross sales, total assets or number of employees for the whole range of firms has also been shown to be fat-tailed with relatively frequent extreme events, where empirical growth rate densities display a characteristic 'tent shape' on a semi-logarithmic scale, implying an exponential power functional form (Amaral et al. 1997; Bottazzi et al. 2001, 2002; Bottazzi & Secchi 2005, 2006; Alfarano & Milaković 2008; Bottazzi et al. 2011; Erlingsson et al. 2013; Mundt et al. 2015). These distributions have frequently been identified as Laplacian (Kotz et al. 2012), which though has recently been challenged theoretically and empirically (Mundt et al. 2015). We stick to the exponential power or Subbotin (1923) shape and focus on the fat-tailed nature of size growth rates.

Concerning the firm age distribution, empirical findings are scarcer. However, the (limited) consensus appears to be that firm age is approximated well by an exponential distribution, as shown by a number of studies: Coad & Tamvada (2008) for several developing countries; Kinsella (2009) for Irish firms; Coad (2010) for the plant level in the US and Daepp et al. (2015) for publicly listed firms in the US. This exponential age distribution also has the crucial theoretical implication that death rates are independent of firm age, as Daepp et al. (2015) confirm empirically.

The main stylised facts which our model aims to replicate are thus: a Zipf law in the upper tail of firm sizes;[1] fat-tailed growth behaviour; and a high frequency of 'superstar' high growth events coupled with an exponential age distribution with a common insolvency probability for all firms, irrespective of age.

2.2.2 Agent-Based Models

Competition within industries, which produces the stylised facts discussed here, constitutes a socio-economic system. To study the dynamics in this system and find candidates for mechanisms that lead to empirically observed facts, an Agent-Based Model (ABM) forms an adequate approach (Klein et al. 2018): Due to competitive interactions between individual firms, one cannot properly describe the system by additive aggregation of the model, but observed phenomena are emergent (Coleman 1990). Agent-Based Models can highlight and explain emergent phenomena and open the black box of competitive interactions on a system level in order to uncover interactions in and structures of subsystems (Hedström & Ylikoski 2010). Given the high level of idealisation, we do not intend to make quantitative predictions, but are nevertheless confident that the model can reveal central qualitative features of its economic target system (Grüne-Yanoff 2009).

2.2.3 An Agent-Based Model of Learning and Selection

We introduce a layer of locality to the model of learning and selection of industrial dynamics by Dosi et al. (2017b).[2] This model understands learning as an increase in productivity by a random factor, as detailed in Section 2.2.4 for details. Gabaix (2009) identifies this stochastic process featuring a multi-

[1] The focus on the upper tail is partially motivated by the fact that about a third of variations in US GDP growth can be explained by the idiosyncratic destinies of the 100 largest firms (Gabaix 2011).

[2] Here, we only describe the basic notion of the benchmark model and our extension. For details and all equations, see Section 2.3.

plicative component as an adequate generating mechanism for the empirically observed power-law distribution of firm size.

Given the resulting heterogeneous and dynamic levels of productivity, market shares are allocated accordingly. Our proposed allocation mechanism makes use of a biological metaphor, the Darwinian ‘survival of the fittest’ principle, now in the form of a ‘replicator dynamics’ approach (Fisher 1930). The fittest or most productive firms grow to dominate the market, while less productive firms fall victim to competition and are driven out (Cantner 2017). In our formal description, we remain agnostic about the precise nature of the mechanism translating productivity increases into growing market shares to allow for a reasonably general application. These translation mechanisms by which higher market shares might accrue due to enhanced productivity include: increased product quality for given unit costs; decreasing unit costs for products of equal quality; freed up funds for increased marketing spending; or any other mechanism.

More specifically, in our representation the market share of a firm grows or shrinks according to how its productivity compares with the weighted average productivity of all firms in the model; thereafter, firms whose shares have fallen below a threshold leave the market and are replaced by new entrants. This constitutes a selective replicator dynamics process for which Cantner & Krüger (2008) as well as Cantner et al. (2012) present empirical evidence.

Dosi et al. (2017b) use these replicator dynamics in their model: Initially, all firms have equal market shares and productivity levels. At each time step, firms increase their productivity by a random factor, following which they gain or lose market share depending on how their own productivity compares with global average productivity. Firms whose share falls below a threshold value are replaced by new entrants. These new entrants start with the market share with which firms were initialised (and shares of all incumbents are adjusted so that the aggregate market size remains constant), but have their productivity level set to the current weighted global average productivity in the model. We carefully extend this model by adding a network layer to capture actual competitive interactions between agents. There are various ABM that emphasise the role of locality in economic interaction (Tesfatsion 2017). Our careful extension allows to gain more specific insights on the impact of localised competition without losing track of the core mechanisms. Hence, we validate the model by showing that the specific case of a complete network, which resembles the model by Dosi et al. (2017b), also displays a similar behaviour and yields the same stylised facts.

2.2.4 Productivity Gain Through Stochastic Learning

Our model features two channels of learning. Firstly, incumbent firms increase their productivity periodically. Secondly, the initial productivity of entrant firms depends on the localised market that they enter and hence they learn from their link neighbours.

The periodical learning describes the efforts of each firm to improve its productivity continually. In economics, the general concept of learning as a belief update justified by self-collected or socially acquired evidence (Zollman 2009) is often understood as a rational endeavour that agents explicitly control, as Evans & Honkapohja (2013) point out in their overview. Moreover, approaches such as Bray & Savin (1986) or Milani (2007) reveal a close connection between learning and rational expectations. While such detailed understanding of learning is appropriate when investigating a learning process itself, a macroscopic approach seems sufficient for a study of industrial dynamics, where the outcome of learning contributes to one of many mechanisms. This macroscopic approach focuses on the productivity gain that any learning activities of firms yield. Thus, the model abstracts from details of the learning process and does not distinguish where (e.g. product improvements, production efficiency, marketing) or how (e.g. new inventions, imitation of others, deliberate management choices) the productivity gain takes place. When abstracting from subject-specific features of learning, one can treat success as being randomly distributed among individual learners and hence understand learning as an increase of productivity by a random factor. This stochastic learning seems to be an appropriate way to capture actual outcomes, as empirical findings are approximately represented (Luttmer 2007). Moreover, replicator dynamics are also consistent with an understanding of learning as imitating more successful others' behaviour. Schlag (1998) demonstrates this analytically by showing that the aggregate population behaviour follows a replicator dynamics whenever agents choose the individually most successful learning rule.

Accordingly, we follow Dosi et al. (2017b) and deliberately keep the learning process purely stochastic - do not explicitly include rational expectations or adaption to other firms - in order to focus on the network structure effects. With a purely stochastic process, we circumvent the problem that the precise form and effect of an innovation is per definition unpredictable and thus resort to much more modest statistical assumptions about the average rate of technological progress (Arrow 1991).

Besides the periodical stochastic learning of incumbent firms, the network layer and namely the localised market entry that it implies constitutes a second implicit mechanism of learning, which depends on asymmetric innovation. ABM studies that employ multiple or asymmetric learning processes in other contexts reveal unexpected system behaviour and have high explanatory power. For example, Klein & Marx (2018) and Klein et al. (2019) show in a model how asymmetric learning and information cascades shape individual estimates of how likely political revolution is. Asymmetric learning also plays a role in iterated games, as Macy & Flache (2002) show. Mayerhoffer (2018) runs a variant of the Hegselmann-Krause bounded confidence model (Hegselmann & Krause 2002) parallel to a network-based opinion update procedure and finds that the coexistence of both learning mechanisms can explain group-specific attitudes towards queerness among adolescents. In their model of Humean moral theory, Will & Hegselmann (2014) also employ explicit and implicit asymmetric learning in parallel. Models of learning and knowledge diffusion in networks also find application in business science, where they can provide explanations for competitive advantage, as Greve (2009) shows for shipbuilders and shipping companies. In these structures, Skilton & Bernardes (2015) find that successful market entry empirically depends on the network layout.

2.3 Model Description

This section provides a content-oriented presentation; for technical details see the commented model, which is appended electronically/publicly available at GitHub[3] and the description following the accompanying ODD protocol.[4]

Parameter	Variable	(Initial) Values	Equation
Population size	N	150	*constant*
Linking probability	p	$0.01 - 1$ (in steps of 0.01)	*constant*
Local market competitors	K	dependent on p	-
Firm Productivity	a	1	(2.1), at entry: (2.6)
Global market share	s	$1/N$	(2.2)
Localised market power	l	$1/K$	(2.4)

Table 2.1: Parameters, initial values and calculation. The interpretation of variables is given in Section 2.3.1.

2.3.1 Model Properties and Initialisation

The model observes a population of 150 firms that constitute an economy. We adopt this intuitively low number from Dosi et al. (2017b), but sensitivity analyses showed that our results also hold for larger populations. In this economy, firms try to maximise their sales revenue by improving their productivity through learning. However, whilst a firm does act rationally, this is only in a bounded manner due to its possession of imperfect information and environmental complexity. Hence, it does not adapt to the behaviour of other firms or form expectations. Undirected links connect some firms, but the firms themselves have no perception of their links.

Links between firms do not mean that they cooperate in research and development or in production; on the contrary, each link represents a direct

[3]The computer simulation was implemented in Netlogo (Wilensky 1999).
[4]We describe the model according to the protocol guidelines by Grimm et al. (2010) and the extension proposed by Müller et al. (2013).

competitive relationship between two firms in their selling of products that are (almost) perfect substitutes for each other. Pellegrino (2019) recently used the same methodology in a general equilibrium setting to identify aggregate trends and welfare costs of market power in the US. Thus, the model adds a level of locality to competition by linking firms. Clusters of densely linked firms represent an industry with aggravated competition. With this modelling approach, we combine two concepts of market structure that have enjoyed great success in the macroeconomic literature: Chamberlinian monopolistic competition (Chamberlin 1949; Robinson 1969) and the concept of a product space first introduced by Hidalgo and Hausman (Hidalgo & Hausmann 2009). From monopolistic competition, we take the notion that market power in differentiated, localised product markets is consistent with strong global competition, as indicated in the Chamberlinian concept by zero long-run profits. From Hidalgo & Hausmann (2009), we take the idea that similarity of products can be formalised by a network structure in a product space, where a network linkage indicates similarity.

In this context, to formalise local monopolistic competition within the product space, a Erdős-Rényi (ER) random network structure (Erdős & Rényi 1960) seems most appropriate because it does not call for an assumption that firms deliberately form competitive links. To generate the random network at initialisation, a link appears between any pair of firms with probability p. This probability is global, exogenously set and constant. $p = 1$ represents the model by Dosi et al. (2017b). One major advantage of ER networks is the myriad of analytical results pertaining to the network structure for different p. We make use of two results in particular. Firstly, the degree distribution of the network is asymptotically Poisson with thin tails (Newman 2005). This result provides assurance that our findings on the fat-tailed nature of growth rates and the size distribution are no artefacts of the network structure we impose, but rather a genuine emergent feature of interaction within the model.[5] Secondly, there almost surely exists a single giant component for the range of network

[5] Note that even though empirical degree distributions are often fat-tailed warranting an explanation on their own (Johnson et al. 2014), there is no reason to impose a specific network structure a priori, as to the best of our knowledge, there exists no evidence on topologies of competition networks. We thus opt for as minimal assumptions as possible, leaving us with ER-type networks.

probabilities between 1% and 100% as the parameter range we consider. All other components have, almost surely, size of order $O(log(N))$, where N is the number of firms. Hence, we can also examine the relevance of highly heterogeneous competitive environments, where the intensity of competition depends on whether or not a firm is connected to the single giant component or not (Erdős & Rényi 1960).

Besides its position in the network, each firm possesses three attributes that may vary over time. Firstly, there is the global market share s, which one can understand as sales revenue generated by each firm; it measures a firm's level of success and ultimately determines its survival. Initial shares of firms are equal: $\forall i(s_i(t_0)) = 1/N$. Secondly, local competition represented by the network structure means that firms also possess a localised market power l, which measures how productive a firm is in comparison with its immediate competitors that are the link-neighbours in our model. There is no immediate relationship between localised market power and sales revenue; high localised market power does not necessarily imply a high global share; for example, firms with great power in a small or unproductive industry may be small at the level of the whole market. Initial localised market powers are calculated following the same logic as global shares $\forall i(l_i(t_0)) = 1/|K_i|$, where K_i is the set containing all link-neighbours of i and i itself. Thirdly, productivity or level of competitiveness a of a firm indicates how well this firm is equipped for selling its products. It includes a firm's technological and business knowledge along with its skill base, but it could also be shaped by a specific demand for products that the firm offers. This attribute improves through learning and in turn, the productivity of a firm impacts the global share and localised market power of the firm itself as well as of other firms. However, for the purposes of our model, firms start with an equal level of competitiveness: $\forall i(a_i(t_0)) = 1$.

2.3.2 Events During the Simulation

The simulation proceeds in discrete time steps, within each of which the following processes take place in sequential order:

1. Learning: Firms (potentially) increase their productivity.

2. Assessment of global shares and localised market powers.

3. Entry and exit: Firms with low global market shares leave the market and new entrants replace them

Learning In the model, learning incorporates all processes that improve a firm‘s level of competitiveness. This includes an intentional quest for innovations in product design, efficiency of production, and supply-chain management as well as marketing. At the same time, according to this concept, a firm can also ‘learn’ if customers grow more interested in its products independent of deliberate actions by the firm (e.g., products become popular due to some trends set by third parties). We subsume this variety of aspects under a firm-specific and idiosyncratic learning mechanism that we take from Dosi et al. (2017b), while the general concept of this learning dates back to earlier work by Dosi et al. (1995) who propose this as a baseline condition in their model. For this multiplicative stochastic process, each firm i determines its productivity a_i as follows:

$$a_i(t) = a_i(t-1)(1 + \pi_i(t)) \tag{2.1}$$

Where $\pi_i(t)$ describes a firm’s learning parameter and is drawn from a rescaled beta distribution with $\alpha = 1.0$, $\beta = 5.0$, $\beta_{min} = 0.0$, $\beta_{max} = 0.3$ and an upper notional limit $\mu_{max} = 0.2$. This notional limit ensures that the maximum productivity growth rate is indeed 0.2, as we fix all drawn values higher than that for the notional limit. Firms do not experience negative learning because their productivity is measured in absolute terms rather than being compared with that of other firms at this stage. Learning in this sense does not entail failures which would imply negative productivity gains. This deliberate modelling choice excludes planning mistakes on the part of individual firm management, and isolates effects generated by the interplay between stochastic learning and market selection. Furthermore, absolute productivity growth depends on the firm’s previous productivity level, meaning that the expected productivity gain grows proportionally to its past productivity. However, learning is independent of firm size, and hence, there is no (direct) amplifier that would reward larger firms with a potential for higher rates of productivity gain.

Assessment of Global Shares A replicator dynamics formulation reproducing the one used by Dosi et al. (2017b) determines the global market share:

$$s_i(t) = s_i(t-1)(1 + \frac{a_i(t) - \overline{a}(t)}{\overline{a}(t)}) \tag{2.2}$$

For any market containing at least two firms, it holds that $0 < s_i(t) < 1$. The global parameter $\overline{a}$ is the weighted average productivity of all firms N in the global market:

$$\overline{a}(t) = \sum_j a_j(t) s_j(t-1) \tag{2.3}$$

A firm's global share depends not only on its own productivity level, but also the weighted productivity levels of all other firms in the market. The weighting ensures that larger rather than smaller firms shape the market more distinctively. The sales revenue of a firm grows (or shrinks) according to how much the productivity level of this firm exceeds (or undercuts) the weighted average productivity level.

Assessment of localised market power The calculation of localised market power l_i is similar to that of global market share:

$$l_i(t) = l_i(t-1)(1 + \frac{a_i(t) - \overline{a_i^L}(t)}{\overline{a_i^L}(t)}) \tag{2.4}$$

However, agents now compare their productivity level only to those of their link neighbours and the firm itself, the set K:

$$\overline{a_i^L}(t) = \sum_{j \in K_i} a_j(t) l_j(t-1) \tag{2.5}$$

Consequently, a completely unconnected firm (i.e., one with a local monopoly on all its products) has a localised market power of 1, while the value for each other firm may be above or below its global share.

Entry and exit When the global share of a firm drops below the threshold of 0.001, it leaves the market. Using the global share rather than the localised market power here makes sense because a firm becomes unprofitable or goes bankrupt if its sales revenue is too low. This may happen even to firms that possess high power in an industry which ultimately proves to be too small and unsustainable, while conversely firms that are small players in a large industry may create a high revenue. Firms leaving the market disappear from the model and also destroy all their links, which improves the local position of their old link-neighbours (i.e., former direct competitors).

Each departing firm is immediately replaced by a new entrant. This entrant links with incumbents and other new entrants with the same probability p used for initial network generation. The global share of entrants is $1/N$, and their localised market power is $1/|K_i|$ (with K_i again being the set of all link-neighbours and the entrant i itself). However, entrants do not start with a low productivity value of 1, but instead acquire the specific productivity level of the industry they enter (or of the whole market as a fallback should the entrant have no links) altered by the common learning parameter:

$$a_i(t_{entry}) = \begin{cases} \overline{a_i^L}(t_{entry}) + \pi_i(t_{entry}) \text{ if } K_i \setminus i \neq \emptyset \\ \overline{a}(t_{entry}) + \pi_i(t_{entry}) \text{ if } K_i \setminus i = \emptyset \end{cases} \tag{2.6}$$

Generally, entrants benefit from past technological and management innovations as well as local market conditions that shape competitiveness in the industries that they enter. Locally stronger incumbents in the industry play a more central role here. The productivity level of link-neighbours weighted by their localised market power reflects this notion. Here, localised market power is used as the weighting instead of global share, because the local importance of an incumbent firm matters for entrants and not absolute sales revenue. This again reflects the boundedly rational nature of our model, where entrants learn indirectly from the experience of local incumbents, particularly in regard to their tacit product domain knowledge (Glauber et al. 2015). Some entrants are uniquely innovative, meaning that they increase their own productivity levels beyond those of their environments.

Because entrants' global shares are higher than those of market leavers, the sum of all global shares now exceeds 1. To correct for this, the share of each firm is reduced proportionally (divided by the sum of all shares).

Likewise, the entry/exit process altered the network structure and thus each firm divides its localised market power by the sum of all localised market powers in K. These adjustments normalise the corresponding values and ensure comparability over time.

2.4 Simulation Results

To ensure comparability, the results presented in this section generally follow the parametrisation in Dosi et al. (2017b): In particular, we opt for 50 Monte Carlo iterations of simulation runs with time-series length $T = 200$ and for $N = 150$ firms each. Given that the trajectories of all aggregate statistics for all linkage probabilities converge to a stationary state very quickly, we present our estimations for $t = 200$ only, but for the pooled Monte Carlo simulation runs. For $p = 1$, which in its model assumptions fully corresponds to the model set-up in Dosi et al. (2017b), we derive results that are also in full qualitative agreement with the results obtained by Dosi et al. (2017b), indicating that we are indeed generalising their case.[6] For all p, we find that the productivity distribution is very heterogeneous with fat tails and hence consistent with Dosi et al. (2017b) and the empirical evidence cited therein. The negative relationship between size and variance in growth rates, though, holds only for $p = 1$ and its neighbourhood, strengthening the case we are building in this section to confirm that the fully connected network is indeed the empirically relevant benchmark.[7] In contrast to non-parametric descriptive statistics, we analyse our three main results by fitting parametric distributions to the data that allow us to examine the generating mechanisms pertaining to the variable in question.

2.4.1 Size Distribution

We find that the upper tail of the firm size distribution (measured by market shares) is for all p characterised by a power-law distribution. The distribution

[6] We are strongly indebted to Giovanni Dosi and Marcelo Pereira for their helpful comments and sharing their code with us to establish this comparability in all subtle details.

[7] The results on the variance-size scaling, as well as the productivity distribution, are available upon request.

cannot be statistically distinguished by standard non-parametric tests such as the Cramér-von-Mises test and the Kolmogorov-Smirnov test from a continuous power-law distribution (Anderson & Darling 1952; Anderson 1962; Smirnov 1948). We report the corresponding test statistics and p-values in Table 3.1 below.

p	**Test Statistic KS**	**p Value KS**	**Test Statistic CvM**	**p Value CvM**
0	0.0496	0.327	0.265	0.171
0.1	0.0165	0.785	0.062	0.802
0.2	0.0225	0.347	0.140	0.421
0.3	0.0218	0.356	0.161	0.357
0.4	0.0124	0.930	0.0428	0.918
0.5	0.0210	0.569	0.0939	0.615
0.6	0.0178	0.935	0.0501	0.876
0.7	0.0196	0.452	0.194	0.279
0.8	0.0149	0.860	0.066	0.776
0.9	0.0211	0.515	0.152	0.383
1	0.0565	0.143	0.320	0.119

Table 2.2: Summary of test statistics and estimated p values for a fitted power-law distribution to the simulated sales shares with p in increments of 0.1 for the whole parameter space. "CvM" refers to the Cramér-von-Mises test, and "KS" to the Kolmogorov-Smirnov test. For both tests and all reported linkage probabilities p, the hypothesis of a power-law cannot be rejected at the usual significance level of 5%.

Furthermore, for all p, the power-law regime spans approximately two orders of magnitude and hence meets the common minimum requirement for a power-law to be present (Stumpf & Porter 2012). This is equivalent to saying that the discrete distribution of shares can be approximated by this Probability Density Function (PDF) for the continuous analogue of this power-law distribution as

$$p(s) \quad = Cs^{-\alpha}, \text{for } s \geq s_{min}, \tag{2.7}$$

where: s_{min} denotes the minimum share from which on the power-law applies; α denotes the characteristic exponent of the power-law distribution, and C is a normalising constant letting the probability density integrate to 1. Notice that $\alpha \geq 1$ is an inverse measure of concentration, where a lower α indicates a higher degree of inequality. Figure 2.1 shows the Complementary Cumulative Distribution Function (CCDF) of the upper tail firm size distribution for three different linkage probabilities. The minimum was determined by the standard procedure in this field first outlined by Clauset et al. (2009), essentially by: fitting a reverse-order-statistic to a power-law with increasing sample sizes; obtaining the Kolmogorov-Smirnov test statistic; and choosing the s_{min} that minimises it. This method has been shown to outperform other methods robustly, such as minimising the Bayesian Information Criterion (Clauset et al. 2009). Indeed, as the non-parametric tests also suggest, all three distributions display an approximately linear behaviour on a double-logarithmic scale (Newman 2005). The slope for each p is approximately α, where a lower α indicates that the CCDF does decay more slowly, indicating a higher concentration with a higher frequency of large shares.

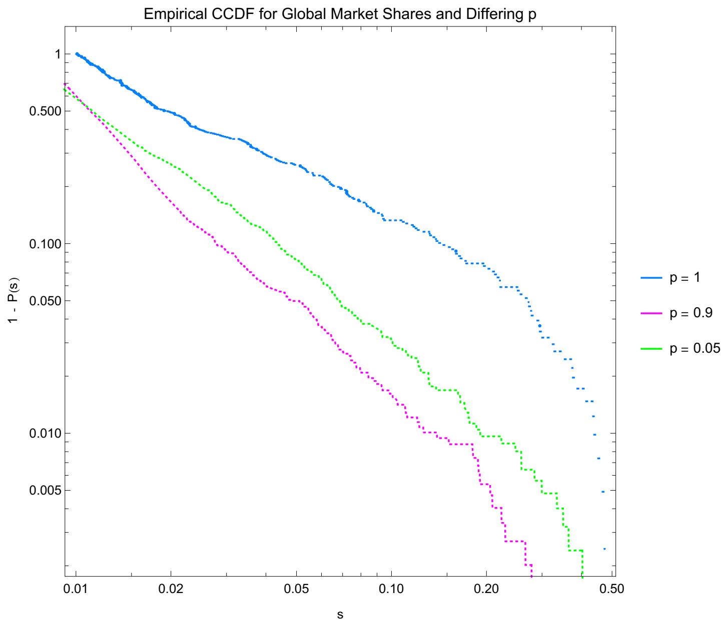

Figure 2.1: Empirical Complementary Cumulative Distribution Function of Firm Sizes for $p = 0.05,\ 0.9$ and 1.

Given the set-up of our model, this is not surprising as it essentially comprises a stochastically multiplicative process with an entry-exit mechanism that has been shown to be the most promising candidate for generating power-laws (Gabaix 2009). Hence, for our set-up the path-dependent stochastically multiplicative process seems to remain the most critical feature of the model, irrespective of the underlying network structure. Moreover, regardless of the underlying mode of local competition, we want to highlight that this extremely heterogeneous power-law distribution implies a situation that is far from the perfect competition usually assumed as a benchmark for general equilibrium models.

The functional form for the upper tail of empirical firm size distributions is thus seemingly broadly consistent with all connectivity patterns for the underlying localised network. However, the empirical consensus that the upper tail of firm sizes is characterised by Zipf's law with an estimated $\hat{\alpha}$ not statistically different from 1 constrains the permissible p to a much more narrow range. In Figure 2.2, we show the behaviour of estimated $\hat{\alpha}$ for the whole range of p in our model using 1% increments and with error bands corresponding to two sample standard deviations upwards and downwards, implying that the plotted intervals span the true α with 95% confidence.[8]

Two features are striking in the plot: Firstly, Zipf's law is consistent only with the two knife-edge scenarios of an extremely sparse network in the (narrow) neighbourhood of $p = 0$ and the other extreme of a very dense network in the (narrow) neighbourhood of $p = 1$. This, in turn, implies that the empirical evidence constrains us to these two extremes. Secondly, contrary to economic intuition built within general equilibrium models, measured concentration is maximal - Zipf - for the highest degree of local competition and lowest for a mild (local) oligopoly around $p = 0.9$.

[8]The estimation of $\hat{\alpha}$ was carried out by using the associated Maximum Likelihood Estimator (MLE) or Hill estimator that has been shown to be less biased compared to OLS methods or fitting a linear function onto the power-law on a double-logarithmic scale. Cf. also Goldstein et al. (2004) for a more rigorous analysis of different graphical methods and their respective shortcomings compared to an MLE. The standard errors were obtained exploiting the asymptotic Gaussianity of the Hill estimator (De Haan & Resnick 1998).

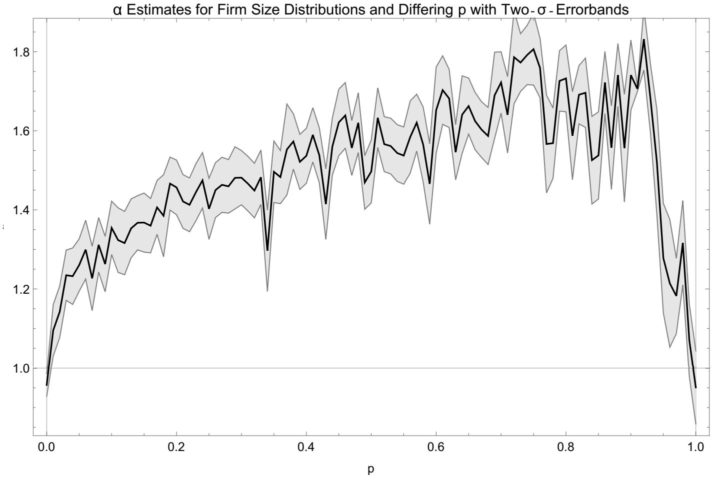

Figure 2.2: Estimated $\hat{\alpha}$ for all p in increments of 1%. Lines between estimates are visual aids only.

2.4.2 Growth Rates of Market Shares

Another focal point of the industrial dynamics literature is the presence of fat-tailed growth rate distributions in sales. In more colloquial terms, this implies that jumps in firms' market shares are relatively more frequent than one would would expect from a Gaussian distribution. Note that the presence of non-Gaussian growth rate distributions alone indicates that the growth process is not independent in time. According to the Central Limit Theorem, this would induce Gaussian growth rates. Of course, stochastically multiplicative growth processes like ours responsible for emergence of the power-law in levels are actually path-dependent and thus violate independence. Indeed, Dosi et al. (2018) produce robust findings which support fat-tailed growth rates for the baseline specification we use together with a vast range of different specifications and parameter constellations. Their baseline model corresponds to our $p = 1$ parametrisation. We also find fat-tailed growth rate distributions for p different than 1, as can be seen for $p = 0.05$ and 0.9 in Figure 2.3. However, at least for the not fully connected network, the fat-tailed nature of growth rates is primarily due to extreme losses, rather than frequent extreme growth events which are at odds with the presence of superstar firms. We want to highlight also that this fat-tailed nature is a different concept from mere 'dispersion'. While dispersion does indeed seem to decline with p, being fat-tailed refers to the frequency of extreme events *relative* to the frequency of events closer to the expected growth rates, for which inference by visual inspection is a much harder task. Within Figure 2.3, frequent extreme growth events are present only for the fully connected network. This finding, though, might merely be an artefact of the three network connectivities under consideration and thus will not hold for the whole parameter space. We need to explore the full parameter space to identify possible switching behaviour concerning the source of fat tails in the simulated growth rate distributions.

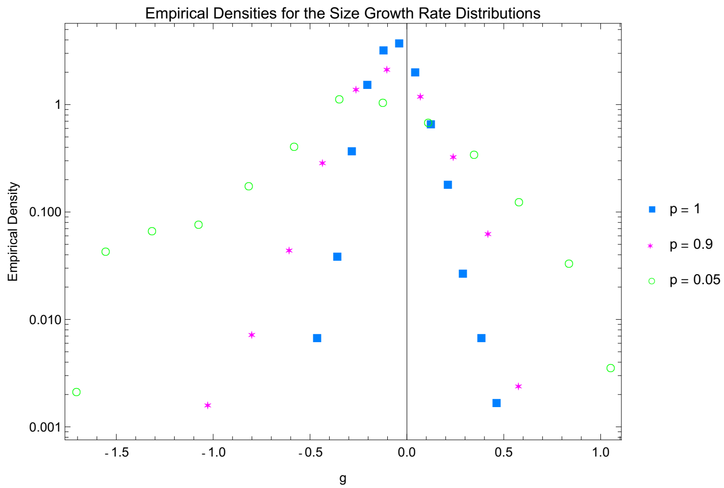

Figure 2.3: Empirical Density of Firm Size Growth Rates g on a semi-logarithmic scale for $p = 0.05,\ 0.9$ and 1.

A standard procedure for identifying fat tails and quantifying the degree of 'fat-tailedness' in growth rate distributions is to fit a Subbotin distribution (Subbotin 1923) to the data and take its shape parameter b as a measure of heavy tails' strength. The Subbotin density includes the Gaussian for $b = 2$, the Laplacian for $b = 1$, the Dirac-Delta for $b \to 0$ (from above), and the uniform distribution for $b \to \infty$ as special cases. Consequently, we define fat-tailed behaviour for all $b \geq 0$ significantly smaller than 2 for the Gaussian case.

As the contemporary relevance of superstar firms is central to our concerns within this study, we are primarily interested in extreme growth events as opposed to extreme losses. We opt for an asymmetric variant of the Subbotin distribution, introduced by Bottazzi (2014), to distinguish extreme growth events from extreme losses. The PDF is given by:

$$p(g; a_r, a_l, b_l, b_r, m) = C^{-1}\text{Exp}\left(-\frac{1}{b_l}\left|\frac{g-m}{a_l}\right|^{b_l}\Theta(m-g) + \frac{1}{b_r}\left|\frac{g-m}{a_r}\right|^{b_r}\Theta(g-m)\right), \quad (2.8)$$

where: $\Theta(\cdot)$ denotes the Heaviside theta function; m is a centrality parameter; a_l and a_r are the scale parameters of the left and right tails, respectively; whilst b_l and b_r are shape parameters for both tails with the analogous interpretation as in the symmetric case. In the language of this distributional analysis, 'superstar-like' behaviour is obtained for relatively frequent extreme growth events, that is, a fat right tail of the growth rate distribution with b_r significantly lower than 2. We estimate both parameters for the growth rate distributions of market shares by MLE for each p in 1% increments. The corresponding standard errors are obtained by utilising the Fisher information (Ruppert 2014).[9] Figure 2.4 shows the values of b_l and b_r as a function of p with p increasing in 1% increments.

[9]In particular, we employ the freeware *Subbotools 1.3.0* specifically designed for the estimation of different flavours of the Subbotin distribution (Bottazzi 2014), which delivered by far the most efficient parameter estimates for different samples of data we simulated.

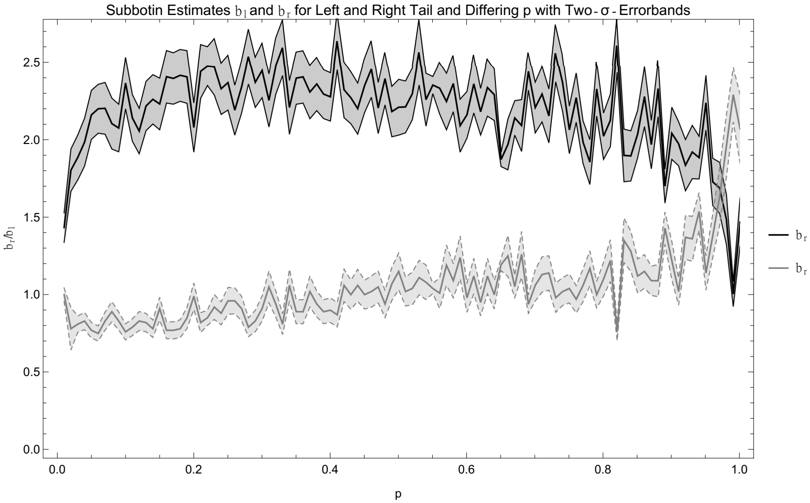

Figure 2.4: Estimated $\hat{b}_l$ and $\hat{b}_r$ for all p in increments of 1%. Black estimates for b_l, gray estimates for b_r. Lines between estimates are visual aids only.

The figure highlights two distinct regimes with respect to the growth rate distributions. Taken as a whole, all growth rate distributions seem to be fat-tailed in agreement with empirical studies. However, the source of this fat-tailed behaviour differs between regimes. While for the broadest range of p between 0 and about 0.93, thus between a completely sparse and a very dense network, relatively frequent *extreme losses* are responsible for the fat tails, the situation changes dramatically in the neighbourhood of a fully connected network, where relatively frequent *extreme growth* dominates. Superstar-like behaviour is thus consistent only with extremely dense networks implied by a p close to 1.

2.4.3 Age

Finally, for age, our model can mimic the empirically observed exponential distribution in age levels for all p. This can be seen in Figure 2.5, where the three age distributions being considered display approximately linear behaviour on a semi-logarithmic scale, consistent with an exponential functional form.[10] This emergent exponential stationary age distribution coupled with stable population levels has, in itself, an important implication: The exit probability or insolvency rate is common and constant for all firms (Artzrouni 1985). Thus, every firm irrespective of its age has the same probability of becoming insolvent in any period and, consequently, has the same expected age. The relatively stable distributions of size and growth rates within time at the meso-level are consistent with a very dynamical economic system underlying these regularities and high rates of 'churning' in the composition of firms, where even local and global market leaders face the same certain prospect of insolvency at some point.

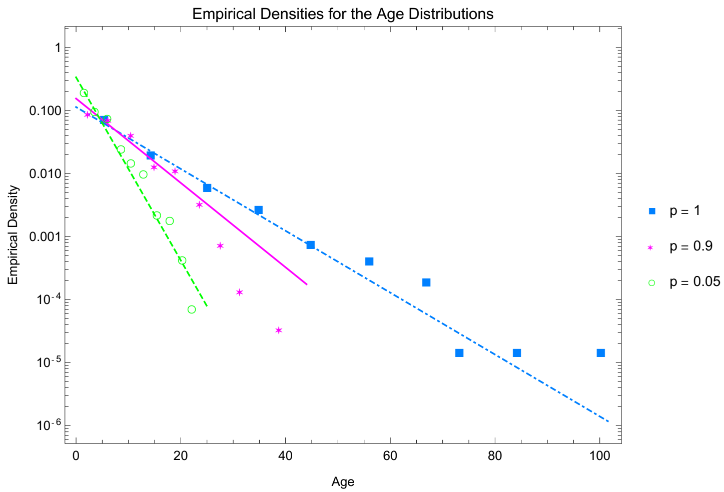

Figure 2.5: Empirical Density of Firm Age on a semi-logarithmic scale for $p = 0.05, 0.9$ and 1 with Exponential Fits obtained by MLE.

While the functional form of the emergent age distribution is constant for different p, its estimated parameter $\hat{\lambda}$ as the insolvency rate changes with p. As can be seen, the firms' life expectancies vary widely with p. For $p = 0.05$, the firms cluster around a very young age, while exhibiting much wider dispersion

[10]The exponential might appear to not fit the age distribution too well for $p = 0.9$. However, this impression is mainly an artefact of the semi-logarithmic scale and pertains only to the largest 0.1% of values. For the remaining 99.9%, the fit is extremely good, leaving us confident that the exponential is a reasonable choice here.

and higher expected age for $p = 1$. Life expectancies thus seem to increase in the network connectivity, but also grow more heterogeneous.

When examining the whole parameter space of p, the insolvency rate falls monotonically with p as we show in Figure 2.6.[11]

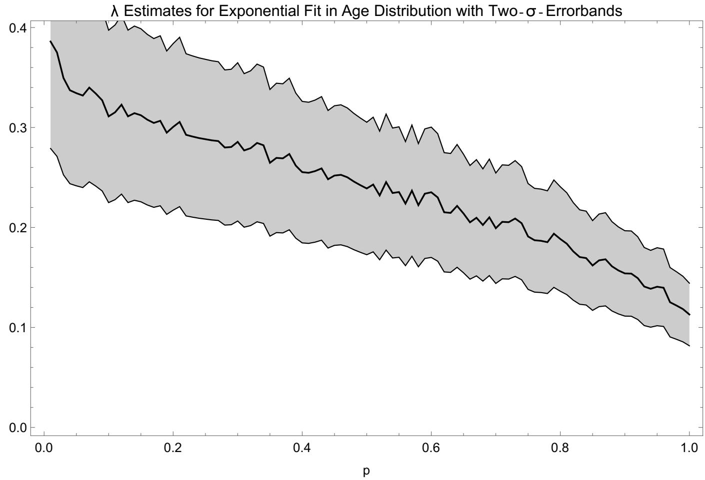

Figure 2.6: Estimated $\hat{\lambda}$ for all p in increments of 1%. Lines between estimates are visual aids only.

Thus, while all firms irrespective of their age face the same estimated insolvency probability $\hat{\lambda}$ per regime or per p, this insolvency probability differs widely between the regimes. Given that expected age is just the inverse of $\hat{\lambda}$, this implies that with a higher p, firms tend to stay in the market for a much longer time, and there is less 'churning' between periods.

2.4.4 Generating Mechanisms

Dosi et al. (2017b) explain their model outcomes based on the idiosyncratic learning process and replicator dynamics; this explanation also straightforwardly applies for the complete network in our model. However, the tails of

[11]The estimated $\hat{\lambda}$ was estimated through MLE. The standard errors were obtained by utilising the fact that $\hat{\lambda}$ is just the inverse of the sample mean and that the associated sample standard deviation is therefore $(\hat{\lambda}\sqrt{N})^{-1}$ (Lehmann & Casella 2006).

the global share distribution, the growth distribution and market exit probability of firms react in a highly elastic way towards changes in the network topology. Thus, these results suggest the presence of a second model mechanism that depends on network density and the implied distribution of localised market power. Because the learning of incumbents and assessment of their global shares work irrespective of network layout, the success of entrants remains the sole candidate for such a driving mechanism.

Since all entrants have identical initial market shares, the individual success of each entrant depends largely on its initial level of competitiveness. To gain a high level of initial competitiveness, an entrant must connect to as many highly productive incumbents with high localised market power as possible (i.e., join a thriving industry). Such connections become less likely for smaller link probabilities p. Thus, in sparse networks, most entrants start with low productivity. Furthermore, since the assessment of global market share compares the productivity of the firm in question with the weighted global average productivity, these relatively unproductive entrants quickly lose market share in the first periods of their lives. That explains the fat left tail of the growth rate distribution for small p.

At the same time, those entrants that connect to highly productive and powerful incumbents have a comparative advantage, increase their sales quickly, and manage to catch up with even the most successful firms in the market. Hence, firms within the power-law tail exhibit more homogeneous sizes, the sparser the network is. The low maximum firm age and high probability of exit for sparse networks is a corollary of these two aspects: Even successful firms are challenged, find themselves outperformed by productive younger competitors and finally leave the market, while most entrants do so after only a few simulation periods. Without explicit targeting, we are able to replicate 'imprinting' behaviour or the empirically well established phenomenon that founding conditions exhibit lasting effects on the entrants' survival probabilities (Geroski et al. 2010).

For higher linking probabilities, the rate of entrants with a high initial productivity level grows, making the left tails of the growth distribution thinner. However, the most productive entrants are also hindered by the higher average productivity level and consequently have a harder time becoming superstars; thus, the inequality within the power-law tail decreases even more.

Furthermore, the importance of the birth productivity mechanism, which favours few entrants and lets many suffer, becomes weaker the denser the network is and hence the more similar localised market power as well as global market share become. If the entrants' fate is no longer determined at birth, learning becomes more important. Thereby, the replicator dynamics of global share assessment means a fat right tail of the growth distribution and tails of the firm size distribution in accordance with Zipf's law.

To summarise, two distinct mechanisms govern the productivity of firms and consequently their commercial success. The first is a process of learning that occurs within each period and is equally strong for all network layouts, but its effects depend on attendant productivity levels. The second mechanism is the allocation of initial productivity based on link-neighbours, which applies only once to each entrant at birth. The mode of operation and the strength of this second mechanism depends to a great extent on network density. For least dense networks, it dooms most of the entrants to a fast market exit while it is at the same time also subsidising a few of them in an extreme way, prolonging their accumulation of market shares. For denser networks, more firms share this subsidy and hence the most successful firms become more equal in terms of their size. Furthermore, it is noteworthy that the second mechanism takes precedence over the first for all but the densest networks, according to simulation outcomes. That is the case because birth productivity also implies a path-dependency: For an unequal birth productivity distribution of entrants, learning stabilises, and amplifies this inequality due to a higher productivity, also meaning a potential for a higher absolute gain through learning.

2.5 Discussion

We introduce a network-structure to the bare-bones model of a 'winner takes most/all' market proposed by Dosi et al. (2017b). This extension generates surprisingly rich dynamics and intriguing implications when deviating from the benchmark of a fully competitive localised market. In particular, we have been looking to highlight both the positive and normative implications we draw from our modelling exercise and their practical relevance for economic regulation as well as management decisions in the case of a single firm.

Empirically, we find that the stylised facts of industrial dynamics, namely Zipf's law in the firm-size distribution and fat-tailed, 'superstar-like' firm growth rates are consistent only with a situation very close to the benchmark of a fully connected network, meaning most intensive localised competition. All other network connectivities lead to significant deviations from the stylised facts in at least one regard. Hence, if we can accurately identify parts of the empirical mechanism – and there exists evidence that replicator dynamics play an essential role in empirical markets (Cantner & Krüger 2008; Cantner et al. 2012), our results will point to product markets that are relatively undifferentiated. Thus, market power comes from global rather than localised dynamics. These results are in stark contrast to our initial expectations of low concentration and high rates of 'churning' for relatively high degrees of localised competition. This indicates that anecdotal insights gained from analysing static frameworks of competition do not necessarily transfer well to situations where strong non-linearities and feedback mechanisms are present.

In our model, the coexistence and partial interaction of two learning mechanisms and replicator dynamics explain the results: (1) stochastic productivity improvements in each period for each incumbent firm constitute the first way of learning; (2) works indirectly at market entry because an entrant's initial productivity depends on the weighted average productivity of the incumbents that it links to, meaning within its specific industry. The less densely connected a network, the fewer entrants form connections to highly productive incumbents; hence, their initial productivity is low, and consequently, their market shares decrease, which explains the fat left tail of growth rate distributions and lower average firm age. However, those entrants connected to highly productive incumbents thrive because their initial productivity is high in comparison to most incumbents. Thus, they can catch up with even the most successful incumbents and market concentration decreases. Methodologically, our model of networked competitive interaction can thus be thought as a complement to the foundational theoretical study by Cantner et al. (2019)

who study collaboration in networks to explain especially the instability of early-lifecycle firms by lock-in effects within suboptimal value chains. Namely, our model suggests a mechanism that may be present in addition to 'failures of selection' (Cantner et al. 2019) and cause the high rates of churning and volatility in market shares of young firms already observed by Mazzucato (1998). We demonstrate that such instability can also emerge for functioning selection and industry-specific initial productivity, as long as markets are locally segregated or, equivalently, the competitive network exhibits rather low density. We aim to investigate the interplay of both the collaborative and competitive network channels in further research.

Since inequalities of initial productivity shrink with increasing network density and do not exist for the complete network, a lower level of competitiveness implies lower market concentration. Furthermore, for the complete network, other sources of inequality in initial productivity could replace the market entry learning mechanism: The absence of inequality in starting conditions leads to the most successful firms acquiring a greater market share. Consequently, one must accept the success of these superstars as an outcome if the aim is to create full equality of opportunity; otherwise, to avoid high market concentration by the most successful firms, one must deliberately create inequality of opportunity. In less abstract terms, our model suggests the common fear that active industrial policy creating unequally favourable starting conditions for specific firms and thus being anticompetitive to be at least partially misguided (cf. Sokol (2014) for a vocal proponent of this view): The relevant metric for consumers is perhaps *ex post* concentration in market shares, indicating that one can accept or even foster *ex ante* inequality in starting conditions to decrease such concentration after the fact. Active industrial policy enhancing the productivity of incumbents can even lead to positive productivity spill-overs, since entrants benefit from the average productivity of the market they enter. The more relevant trade-off within such markets appears to be between decreasing concentration in market power (lowering p) or decreasing the amount of turnover in the market (increasing p), with 'turnover' typically also implying (transient) increases in unemployment and the destruction of firm-specific capital and knowledge. In this way, our model can help to identify the relevant trade-offs for regulatory policy and contribute to a richer view apart from standard static efficiency considerations.

Besides these global findings, the model also suggests that there are localised cycles of productivity and firm size: If incumbents have acquired high localised market power and a high productivity level, new entrants joining the market segment and engaging in competitive interaction (i.e., linking to the productive incumbents) also start with a high productivity rate. Consequently, the industry in question becomes even more productive until it overheats, and incumbents are repressed from the market while the high productivity shifts to another (possibly new), related market segment. This effect is entirely in line with the empirical study, in which Schlichte et al. (2019) show that the timing of entry to highly specified submarkets between two technology waves is crucial for the success of new firms. Moreover, our model supports their finding that there is a first-follower advantage (in our model represented by successful entrants) as opposed to a first-mover advantage (moderately successful incumbents that are nonetheless outperformed by entrants) because of growing consumer acceptance of new technology (Davis 1989). These findings might be of particular interest to practitioners in Venture Capital and are consistent with their empirical emphasis on 'deal selection' compared to other phases of the investment process (Gompers et al. 2020). However, there exists no consensus on the correct selection strategy, with some trend-following venture capitalists selecting 'hot sectors' and other contrarian ones avoiding them (Gompers et al. 2020). In principle, our model points to the trend-following strategy to benefit from the high initial local productivity of the relevant submarket. This is still no guarantee for success, though, as the submarket in question might be on the brink of overheating, also providing a rationale for the contrarian view. Venture capitalists, in our model, should thus pick sectors with high expected *growth* in contrast to present size in *levels* to avoid entering markets near the end of a technology wave.

The validity of our model depends to a great extent on the validity of the baseline model by Dosi et al. (2017b), which we assume to be given. However, since we re-implement the mechanisms from scratch and include the baseline model as a special case reproducing its findings, we can affirm the internal validity of the baseline model and our extension. With regard to external validity, we hope that including a network structure of localised competition can facilitate resemblance (Mäki 2009) between model and real-world economies. Our explanans can actually be true and the cause for the observed empirical fact. Hence, our proposed mechanism fulfils the minimum conditions for a good epistemically possible how-possibly explanation formulated by Grüne-Yanoff & Verreault-Julien (2021). Nevertheless, with the inclusion of localised market power, the nature of our model and thus, the implied mode of analysis remains highly stylised. Hence, the validity of the model is based on its "qualitative agreement with empirical macrostructures" (Fagiolo et al. 2019, p. 771), namely the replication of the stylised empirical facts that our model successfully attempts. Put differently, we develop a specific parallel reality (Sugden 2009) that features generating mechanisms for empirical findings in our reality and hence our results present a candidate explanation for the stylised empirical facts (Epstein 1999). Consequently, there may be different, more adequate, parallel realities featuring either these or even better mechanisms, despite to the best of our knowledge there being no existing models that fulfil these characteristics.

Alternative mechanisms firstly concern the network that we use. While we test for any network density, we limit ourselves to random link formation as we are not aware of empirical evidence for any specific network topology in our context. However, a non-random (e.g., preferential attachment or spatial-dependent) link formation may impact simulation results, especially for low network densities. Moreover, we distinctly interpret links as indicators for localised competition that only matters for a firm's initial productivity level. One could further explicate such localised competition and track it over time. Alternative or additional layers of links could also represent cooperation between firms or their products being complements. Our model's most apparent limitation concerns the baseline replicator dynamics equation, though, which implies that the emergent concentration is 'good concentration' (Covarrubias et al. 2020) and fully justifiable by productivity differences. Empirically, it is questionable if concentration indeed only reflects productivity (Covarrubias et al. 2020), with firms erecting artificial barriers to entry or acquiring competitors and discontinuing their innovative product lines in so-called 'killer acquisitions' (Cunningham et al. 2021) leading to 'bad concentration'. Since it is at least conceivable that a high concentration of the good type is preferable to lower bad concentration, the inclusion of strategic anticompetitive behaviour might alter the policy conclusions of our model and tilt them more towards antitrust measures, which might like in our baseline model induce high ex-post concentration purely based on productivity differences.

Furthermore, the stylised nature of our findings points to obvious extensions and avenues for further research. To analyse not only the consistency with stylised facts, but also for quantitative predictions and even policy experiments, the ABM community has recently developed certain new methods. These are aimed at bringing modelling closer to the data and calibrating parameters (Hassan et al. 2010), particularly by utilising the Method of Simulated Moments (Gourieroux et al. 1996) and related approaches (Bargigli et al. 2018). Given the partial equilibrium nature of our model, this would probably also necessitate allowing for a variable total number of firms over time by including mergers & acquisitions as well as consumer demand, a state sector and even financial markets for meaningful policy experiments. With the benchmark model by Dosi et al. (2017b), this was attempted by the K+S ABM (Dosi et al. 2010). An extension of this sort would enable us in future research to conduct policy experiments and quantify welfare effects for different market structures.

We believe our model to be a valuable contribution to the discussion on market structures and a key step towards a unifying explanation for both the microeconometric evidence on 'superstar' firms and the distributional findings in industrial dynamics. To the best of our knowledge, these two strands of literature have not as yet been linked. We find that for the replicator dynamics approach from industrial dynamics to be consistent with the existence of superstar firms, shown by mircoeconometric studies, there needs to be an almost perfect level of competition. These outcomes emerge because in each simulation period, the firms improve their productivity by idiosyncratic stochastic learning, while new entrants adopt the specific productivity level of their sub-market (i.e., the productivity of their immediate competitors weighted by localised market power). Thus, the model suggests that new firms are most successful if they join existing, highly productive submarkets with high growth potential. Accordingly, while accepting bounds on rationality, we can single out the strategy which a perfectly rational market entrant would pick when faced with a certain market structure. This not only fosters an understanding of market dynamics, but can also be applied to highlight the importance of market intelligence for the management in new firms and new technology markets.

References

Akerman, A., Leuven, E. & Mogstad, M. (2021). Information Frictions, Broadband Internet and the Relationship between Distance and Trade. *American Economic Journal: Applied Economics*, *forthcoming*

Alfarano, S. & Milaković, M. (2008). Does classical competition explain the statistical features of firm growth? *Economics Letters*, *101*(3), 272 – 274

Amaral, L. A. N., Buldyrev, S. V., Havlin, S., Maass, P., Salinger, M. A., Stanley, H. E. & Stanley, M. H. (1997). Scaling behavior in economics: The problem of quantifying company growth. *Physica A: Statistical Mechanics and its Applications*, *244*(1), 1 – 24

Anderson, T. W. (1962). On the distribution of the two-sample Cramer-von Misés criterion. *The Annals of Mathematical Statistics*, (pp. 1148–1159)

Anderson, T. W. & Darling, D. A. (1952). Asymptotic theory of certain "goodness of fit" criteria based on stochastic processes. *The Annals of Mathematical Statistics*, *23*(2), 193–212

Arrow, K. (1991). The dynamics of technological change. In *Technology and Productivity: The Challenge for Economic Policy*, (pp. 473–476). OECD Paris, France

Artzrouni, M. (1985). Generalized stable population theory. *Journal of Mathematical Biology*, *21*(3), 363–381

Autor, D., Dorn, D., Katz, L. F., Patterson, C. & Van Reenen, J. (2020). The fall of the labor share and the rise of superstar firms. *The Quarterly Journal of Economics*, *135*(2), 645–709

Axtell, R. L. (2001). Zipf distribution of US firm sizes. *Science*, *293*(5536), 1818–1820

Bargigli, L., Riccetti, L., Russo, A. & Gallegati, M. (2018). Network calibration and metamodeling of a financial accelerator agent based model. *Journal of Economic Interaction and Coordination*, (pp. 1–28)

Böhm, F. (1960). Demokratie und unternehmerische Macht. In Institut für ausländisches und internationales Wirtschaftsrecht (Ed.), *Kartelle und Monopole im modernen Recht*, (pp. 1–24). C. F. Müller

Bottazzi, G. (2014). Subbotools user's manual. *Laboratory of Economics and Management Working Paper Series, Sant'Anna School of Advanced Studies, Pisa (Italy)*

Bottazzi, G., Cefis, E. & Dosi, G. (2002). Corporate growth and industrial structures: some evidence from the Italian manufacturing industry. *Industrial and Corporate Change*, *11*(4), 705–723

Bottazzi, G., Coad, A., Jacoby, N. & Secchi, A. (2011). Corporate growth and industrial dynamics: Evidence from French manufacturing. *Applied Economics*, *43*(1), 103–116

Bottazzi, G., Dosi, G., Lippi, M., Pammolli, F. & Riccaboni, M. (2001). Innovation and corporate growth in the evolution of the drug industry. *International Journal of Industrial Organization*, *19*(7), 1161–1187

Bottazzi, G. & Secchi, A. (2005). Growth and diversification patterns of the worldwide pharmaceutical industry. *Review of Industrial Organization*, *26*(2), 195–216

Bottazzi, G. & Secchi, A. (2006). Explaining the distribution of firm growth rates. *The RAND Journal of Economics*, *37*(2), 235–256

Bray, M. M. & Savin, N. E. (1986). Rational Expectations Equilibria, Learning, and Model Specification. *Econometrica*, *54*(5), 1129–1160
URL `http://www.jstor.org/stable/1912325`

Brock, W. (1999). Scaling in economics: a reader's guide. *Industrial and Corporate Change*, *8*(3), 409–446. doi:10.1093/icc/8.3.409
URL `http://dx.doi.org/10.1093/icc/8.3.409`

Cantner, U. (2017). Foundations of economic change: An extended Schumpeterian approach. In *Foundations of Economic Change*, (pp. 9–49). Springer

Cantner, U., Krüger, J. J. & Söllner, R. (2012). Product quality, product price, and share dynamics in the German compact car market. *Industrial and Corporate Change*, *21*(5), 1085–1115. doi:10.1093/icc/dts002
URL `http://dx.doi.org/10.1093/icc/dts002`

Cantner, U. & Krüger, J. J. (2008). Micro-heterogeneity and aggregate productivity development in the German manufacturing sector. *Journal of*

Evolutionary Economics, *18*(2), 119–133. doi:10.1007/s00191-007-0079-z URL http://dx.doi.org/10.1007/s00191-007-0079-z

Cantner, U., Savin, I. & Vannuccini, S. (2019). Replicator dynamics in value chains: explaining some puzzles of market selection. *Industrial and Corporate Change*, *28*(3), 589–611

Chamberlin, E. H. (1949). *Theory of monopolistic competition: A re-orientation of the theory of value.* Oxford University Press, London

Clauset, A., Shalizi, C. R. & Newman, M. E. (2009). Power-law distributions in empirical data. *SIAM review*, *51*(4), 661–703

Coad, A. (2010). Investigating the exponential age distribution of firms. *Economics: The Open-Access, Open-Assessment E-Journal*, *4*

Coad, A. & Tamvada, J. P. (2008). The growth and decline of small firms in developing countries. *Papers on Economics and Evolution, Max-Planck-Institut für Ökonomik*

Coleman, J. S. (1990). *Metatheory: Explanation in social science*, (pp. 1–23). The Belknap Press of Harvard University Press

Covarrubias, M., Gutiérrez, G. & Philippon, T. (2020). From Good to Bad Concentration? US Industries over the past 30 years. *NBER Macroeconomics Annual*, *34*(1), 1–46

Cunningham, C., Ederer, F. & Ma, S. (2021). Killer acquisitions. *Journal of Political Economy*, *129*(3), 649–702

Daepp, M. I., Hamilton, M. J., West, G. B. & Bettencourt, L. M. (2015). The mortality of companies. *Journal of The Royal Society Interface*, *12*(106), 20150120

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319–340 URL http://www.jstor.org/stable/249008

De Haan, L. & Resnick, S. (1998). On asymptotic normality of the Hill estimator. *Stochastic Models*, *14*(4), 849–866

Di Giovanni, J. & Levchenko, A. A. (2013). Firm entry, trade, and welfare in Zipf's world. *Journal of International Economics*, *89*(2), 283–296

di Giovanni, J., Levchenko, A. A. & Rancière, R. (2011). Power laws in firm size and openness to trade: Measurement and implications. *Journal of International Economics*, *85*(1), 42 – 52

Dold, M. & Krieger, T. (2019). *Ordoliberalism and European Economic Policy: Between Realpolitik and Economic Utopia*. Routledge

Dosi, G., Fagiolo, G., Napoletano, M. & Roventini, A. (2013). Income distribution, credit and fiscal policies in an agent-based Keynesian model. *Journal of Economic Dynamics and Control*, *37*(8), 1598 – 1625

Dosi, G., Fagiolo, G., Napoletano, M., Roventini, A. & Treibich, T. (2015). Fiscal and monetary policies in complex evolving economies. *Journal of Economic Dynamics and Control*, *52*, 166 – 189. doi:https://doi.org/10.1016/j.jedc.2014.11.014
URL `http://dx.doi.org/https://doi.org/10.1016/j.jedc.2014.11.014`

Dosi, G., Fagiolo, G. & Roventini, A. (2010). Schumpeter meeting Keynes: A policy-friendly model of endogenous growth and business cycles. *Journal of Economic Dynamics and Control*, *34*(9), 1748–1767

Dosi, G., Marsili, O., Orsenigo, L. & Salvatore, R. (1995). Learning, market selection and the evolution of industrial structures. *Small Business Economics*, *7*(6), 411–436. doi:10.1007/BF01112463
URL `http://dx.doi.org/10.1007/BF01112463`

Dosi, G., Napoletano, M., Roventini, A. & Treibich, T. (2017a). Micro and macro policies in the Keynes + Schumpeter evolutionary models. *Journal of Evolutionary Economics*, *27*(1), 63–90

Dosi, G., Pereira, M. C. & Virgillito, M. E. (2017b). The footprint of evolutionary processes of learning and selection upon the statistical properties of industrial dynamics. *Industrial and Corporate Change*, *26*(2), 187–210

Dosi, G., Pereira, M. C. & Virgillito, M. E. (2018). On the robustness of the fat-tailed distribution of firm growth rates: a global sensitivity analysis. *Journal of Economic Interaction and Coordination*, *13*(1), 173–193

Epstein, J. M. (1999). Agent-based computational models and generative social science. *Complexity*, *4*(5), 41–60

Erdős, P. & Rényi, A. (1960). On the evolution of random graphs. *Publ. Math. Inst. Hung. Acad. Sci*, *5*(1), 17–60

Erlingsson, E. J., Alfarano, S., Raberto, M. & Stefánsson, H. (2013). On the distributional properties of size, profit and growth of Icelandic firms. *Journal of Economic Interaction and Coordination*, *8*(1), 57–74

Evans, G. W. & Honkapohja, S. (2013). *Learning as a rational foundation for macroeconomics and finance*, vol. 68. Princeton University Press

Fagiolo, G., Guerini, M., Lamperti, F., Moneta, A. & Roventini, A. (2019). Validation of Agent-Based Models in Economics and Finance. In C. Beisbart & N. J. Saam (Eds.), *Computer Simulation Validation: Fundamental Concepts, Methodological Frameworks, and Philosophical Perspectives*, (pp. 763–787). Cham: Springer International Publishing. doi:10.1007/978-3-319-70766-2_31
URL http://dx.doi.org/10.1007/978-3-319-70766-2_31

Fisher, R. (1930). *The Genetical Theory of Natural Selection.* Clarendon Press, Oxford.

Fujiwara, Y., Di Guilmi, C., Aoyama, H., Gallegati, M. & Souma, W. (2004). Do Pareto–Zipf and Gibrat laws hold true? An analysis with European firms. *Physica A: Statistical Mechanics and its Applications*, *335*(1-2), 197–216

Gabaix, X. (2009). Power laws in economics and finance. *Annu. Rev. Econ.*, *1*(1), 255–294

Gabaix, X. (2011). The Granular Origins of Aggregate Fluctuations. *Econometrica*, *79*(3), 733–772

Gabaix, X. & Landier, A. (2008). Why has CEO pay increased so much? *The Quarterly Journal of Economics*, *123*(1), 49–100

Geroski, P. A., Mata, J. & Portugal, P. (2010). Founding conditions and the survival of new firms. *Strategic Management Journal*, *31*(5), 510–529
URL https://onlinelibrary.wiley.com/doi/abs/10.1002/smj.823

Glauber, J., Wollersheim, J., Sandner, P. & Welpe, I. M. (2015). The patenting activity of German Universities. *Journal of Business Economics*, *85*(7), 719–757

Goldstein, M. L., Morris, S. A. & Yen, G. G. (2004). Problems with fitting to the power-law distribution. *The European Physical Journal B-Condensed Matter and Complex Systems*, *41*(2), 255–258

Gompers, P. A., Gornall, W., Kaplan, S. N. & Strebulaev, I. A. (2020). How do venture capitalists make decisions? *Journal of Financial Economics*, *135*(1), 169–190

Gourieroux, M., Gourieroux, C., Monfort, A. & Monfort, D. A. (1996). *Simulation-based econometric methods.* Oxford University Press

Greve, H. R. (2009). Bigger and safer: the diffusion of competitive advantage. *Strategic Management Journal*, *30*(1), 1–23. doi:10.1002/smj.721
URL http://dx.doi.org/10.1002/smj.721

Grimm, V., Berger, U., DeAngelis, D. L., Polhill, J. G., Giske, J. & Railsback, S. F. (2010). The ODD protocol: a review and first update. *Ecological Modelling*, *221*(23), 2760–2768

Grüne-Yanoff, T. & Verreault-Julien, P. (2021). How-possibly explanations in economics: anything goes? *Journal of Economic Methodology*, *28*(1), 114–123. doi:10.1080/1350178X.2020.1868779
URL http://dx.doi.org/10.1080/1350178X.2020.1868779

Grüne-Yanoff, T. (2009). Learning from minimal economic models. *Erkenntnis*, *70*(1), 81–99

Hassan, S., Pavón, J., Antunes, L. & Gilbert, N. (2010). Injecting Data into Agent-Based Simulation. In K. Takadama, C. Cioffi-Revilla & G. Deffuant (Eds.), *Simulating Interacting Agents and Social Phenomena*, (pp. 177–191). Tokyo: Springer Japan

Hedström, P. & Ylikoski, P. (2010). Causal Mechanisms in the Social Sciences. *Annual Review of Sociology*, *36*(1), 49–67. doi:10.1146/annurev.soc.012809.102632
URL http://dx.doi.org/10.1146/annurev.soc.012809.102632

Hegselmann, R. & Krause, U. (2002). Opinion dynamics and bounded confidence models, analysis, and simulation. *Journal of Artificial Societies and Social Simulation*, *5*(3)

Heinrich, T. & Dai, S. (2016). Diversity of firm sizes, complexity, and industry structure in the Chinese economy. *Structural Change and Economic Dynamics*, *37*, 90–106

Hidalgo, C. A. & Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, *106*(26), 10570–10575

Johnson, S. L., Faraj, S. & Kudaravalli, S. (2014). Emergence of power laws in online communities: The role of social mechanisms and preferential attachment. *MIS Quarterly*, *38*(3), 795–808

Kaldor, N. (1961). Capital accumulation and economic growth. In *The Theory of Capital*, (pp. 177–222). Springer

Kang, S. H., Jiang, Z., Cheong, C. & Yoon, S.-M. (2011). Changes of firm size distribution: The case of Korea. *Physica A: Statistical Mechanics and its Applications*, *390*(2), 319–327

Kinsella, S. (2009). The age distribution of firms in Ireland, 1961–2009. *Department of Economics, University of Limerick, Ireland*

Klein, D. & Marx, J. (2018). Wenn Du gehst, geh ich auch! Die Rolle von Informationskaskaden bei der Entstehung von Massenbewegungen. *PVS Politische Vierteljahresschrift*, *58*(4), 560–592

Klein, D., Marx, J. & Fischbach, K. (2018). Agent-Based Modeling in Social Science, History, and Philosophy. An Introduction. *Historical Social Research/Historische Sozialforschung*, *43*(1 (163), 7–27

Klein, D., Marx, J. & Scheller, S. (2019). *Rational Choice and Asymmetric Learning in Iterated Social Interactions – Some Lessons from Agent-Based Modeling*, (pp. 277–294). Springer

Kotz, S., Kozubowski, T. & Podgorski, K. (2012). *The Laplace distribution and generalizations: a revisit with applications to communications, economics, engineering, and finance.* Springer Science & Business Media

Lehmann, E. L. & Casella, G. (2006). *Theory of point estimation.* Springer Science & Business Media

Luttmer, E. G. (2007). Selection, growth, and the size distribution of firms. *The Quarterly Journal of Economics*, *122*(3), 1103–1144

Macy, M. W. & Flache, A. (2002). Learning dynamics in social dilemmas. *Proceedings of the National Academy of Sciences*, *99*(suppl 3), 7229–7236

Mäki, U. (2009). MISSing the World. Models as Isolations and Credible Surrogate Systems. *Erkenntnis*, *70*, 29–43

Mayerhoffer, D. M. (2018). Raising Children to Be (In-)Tolerant: Influence of Church, Education, and Society on Adolescents' Stance towards Queer People in Germany. *Historical Social Research*, *43*(1), 144–167

Mazzucato, M. (1998). A computational model of economies of scale and market share instability. *Structural Change and Economic Dynamics*, *9*(1), 55–83

Milani, F. (2007). Expectations, learning and macroeconomic persistence. *Journal of Monetary Economics*, *54*(7), 2065–2082

Müller, B., Bohn, F., Dreßler, G., Groeneveld, J., Klassert, C., Martin, R., Schlüter, M., Schulze, J., Weise, H. & Schwarz, N. (2013). Describing human decisions in Agent-Based Models-ODD+ D, an extension of the ODD protocol. *Environmental Modelling & Software*, *48*, 37–48

Mundt, P., Alfarano, S. & Milaković, M. (2015). Gibrat's Law Redux: think profitability instead of growth. *Industrial and Corporate Change*, *25*(4), 549–571

Newman, M. J. E. (2005). Power Laws, Pareto Distributions and Zipf's law. *Contemporary Physics*, *4*, 323–351

Okuyama, K., Takayasu, M. & Takayasu, H. (1999). Zipf's law in income distribution of companies. *Physica A: Statistical Mechanics and its Applications*, *269*(1), 125–131

Pascoal, R., Augusto, M. & Monteiro, A. M. (2016). Size distribution of Portuguese firms between 2006 and 2012. *Physica A: Statistical Mechanics and its Applications*, *458*, 342–355

Pellegrino, B. (2019). Product Differentiation, Oligopoly, and Resource Allocation. *WRDS Research Paper*

Robinson, J. (1969). *The economics of imperfect competition.* Springer

Ruppert, D. (2014). *Statistics and Finance: An introduction.* Springer

Schlag, K. H. (1998). Why Imitate, and If So, How?: A Boundedly Rational Approach to Multi-armed Bandits. *Journal of Economic Theory*, *78*(1), 130 – 156. doi:https://doi.org/10.1006/jeth.1997.2347
URL `http://dx.doi.org/https://doi.org/10.1006/jeth.1997.2347`

Schlichte, F., Junge, S. & Mammen, J. (2019). Being at the right place at the right time: does the timing within technology waves determine new venture success? *Journal of Business Economics*, *89*(8), 995–1021. doi:10.1007/s11573-019-00947-0
URL `http://dx.doi.org/10.1007/s11573-019-00947-0`

Silvestre, J. (1993). The market-power foundations of macroeconomic policy. *Journal of Economic Literature*, *31*(1), 105–141

Skilton, P. F. & Bernardes, E. (2015). Competition network structure and product market entry. *Strategic Management Journal*, *36*(11), 1688–1696. doi:10.1002/smj.2318
URL `http://dx.doi.org/10.1002/smj.2318`

Smirnov, N. (1948). Table for estimating the goodness of fit of empirical distributions. *The Annals of Mathematical Statistics*, *19*(2), 279–281

Sokol, D. D. (2014). Tensions between antitrust and industrial policy. *Geo. Mason L. Rev.*, *22*, 1247

Stumpf, M. P. & Porter, M. A. (2012). Critical truths about power laws. *Science*, *335*(6069), 665–666

Subbotin, M. T. (1923). On the law of frequency of error. *Matematicheskii Sbornik*, *31*(2), 296–301

Sugden, R. (2009). Credible worlds, capacities and mechanisms. *Erkenntnis*, *70*(1), 3–27

Tesfatsion, L. (2017). Modeling economic systems as locally-constructive sequential games. *Journal of Economic Methodology*, *24*(4), 384–409. doi: 10.1080/1350178X.2017.1382068
URL `http://dx.doi.org/10.1080/1350178X.2017.1382068`

Wilensky, U. (1999). Center for connected learning and computer-based modeling. In *NetLogo*. Northwestern University

Will, O. & Hegselmann, R. (2014). *Modeling Hume's theory of norm emergence*, (pp. 68–80). Oxford Scholarship Online

Zhang, J., Chen, Q. & Wang, Y. (2009). Zipf distribution in top Chinese firms and an economic explanation. *Physica A: Statistical Mechanics and its Applications*, *388*(10), 2020–2024

Zipf, G. K. (1949). *Human behavior and the principle of least effort.* Boston: Addison-Wesley Press

Zollman, K. J. S. (2009). The Epistemic Benefit of Transient Diversity. *Erkenntnis*, *72*(1). doi:{10.1007/s10670-009-9194-6}
URL `http://dx.doi.org/{10.1007/s10670-009-9194-6}`

3

On the Fate of Protests: Dynamics of Social Activation and Topic Selection Online and in the Streets

Joint work with A. Asgharpourmasouleh, M. Fattahzadeh and J. Lorenz.

Asgharpourmasouleh, A., Fattahzadeh, M., Mayerhoffer, D., Lorenz, J. (2020). On the Fate of Protests: Dynamics of Social Activation and Topic Selection Online and in the Streets. In: Deutschmann, E., Lorenz, J., Nardin, L., Natalini, D., Wilhelm, A. (eds) *Computational Conflict Research*. Computational Social Sciences. Springer, Cham. https://doi.org/10.1007/978-3-030-29333-8_7

The work was initiated on the BIGSSS Summer School in Computational Social Science 2018 at Jacobs University Bremen funded by Volkswagen Foundation (Grant Number 92145). We thank all experts and participants for their feedback. The work is also part of Jan Lorenz' project on Opinion Dynamics and Collective Decision funded by the German Research Foundation (DFG grant number 265108307) which covered the travel cost for Asgharpourmasouleh and Fattahzadeh.

Abstract

This paper studies individual and network conditions for the emergence of large social protests in an agent-based model. We use two recent examples from Iran and Germany to inform the modeling process. In our agent-based model, people, who are interconnected in networks, interact and exchange their concerns on a finite number of topics. They may start to protest either because of their concern or because the fraction of protesters in their social contacts exceeds their protest threshold. In contrast to many other models of social protest, we also study the coevolution of topics of concern in the not (yet) protesting public. Given that often a small number of citizens starts a protest, its fate depends not only on the dynamics of social activation but also on the buildup of concern with respect to competing topics. Nowadays, this buildup happens decentralized through social media. The model reproduces characteristic patterns of the evolution of the two empirical cases of social protests in Iran and Germany. In particular, our results show that positions of agents with certain concern levels on certain topics within the networks are important for the fate of protests.

Keywords Opinion dynamics, Social protest, Social media, Social network

Contents of this Paper

3.1 Introduction

Street protests frequently happen all over the world. In the USA alone, from January 20, 2017 to June 16, 2019, 13,761 protests with 10,827,646 attendees have been recorded (Count Love 2019). Street protests are typical examples of emergent social phenomena that result from the interaction of many heterogeneous and autonomous agents. Changes in the number of attendees and topics of protest are inherent in street protests as the case of Russia from 2007 to 2013 shows (Lankina 2014). By topic of protest, we mean the main issue that protesters address in a protest. After the emergence of a protest, slogans and behavior of protesters, peaceful or violent, influence how others judge it and may constrain more people from joining.

New technologies, specifically social media, have changed our communication. They made cheap and fast interactions among a large number of actors in a decentralized ways possible (assuming that administrators of social media do not intervene in interactions). These technologies have helped to organize protests. A protest announcement can reach millions in no time without central control. Moreover, they have enabled amateur multimedia reporters to broadcast details of the protest in real time.

On the other hand, social media is not only a place for announcing street protests or sharing information about these. Social media is also a place for genuinely digital protest in the form of campaigns and conflicts among users. In this chapter, we address the mutual relationship between street protests and their perception by the public. A significant part of this perception emerges in the media in general and in social media in particular (Elson et al. 2012; Anstead & O'Loughlin 2014). Not everyone is active in social media, and users do not publish all their ideas. Nevertheless, social media still captures reasonably how people perceive a street protest, due to the large number of users and their somewhat equal share of power.

The role of social media in the emergence of conflicts has been well studied considering street protests and social media as intercorrelated and interdependent (Ayres 1999; Gerbaudo 2012; Valenzuela et al. 2012; Penney & Dadas 2014; Qi et al. 2016). Hussain & Howard (2013) show that mobile phone usage had a crucial role in the success of the Arab Spring social movements, while social media helped to expand it (Lim 2012; Howard et al. 2011). In the Philippines, during the 2001 protest, again, mobile messaging played a prominent role as the place and time of the protest were coordinated through text messages (Shirky 2011). In the case of Occupy Wall Street, Twitter, Facebook, and YouTube played a significant role (DeLuca et al. 2012). These media are successful in mobilizing people since their decentralized structure allows for large-scale cascades of messages (González-Bailón et al. 2011). They also have a leading role in the first stages of protests. When traditional media start covering these protests, social media effects mix with those of traditional media (González-Bailón et al. 2013).

The majority of the previous studies focused on how social media has helped to mobilize potential attendees of protests. However, only a few have focused on the interplay between street protests and their image in social media and recognized mobile communication as a context for the creation of counter-narratives in street protests. One example is Neumayer & Stald (2014), who studied cases in Denmark and Germany.

We will model the internal dynamics of typical street protests and their relationships with the perception of the broader public who is active on social media. The simultaneous changes in a protest, in terms of the number of attendees and slogans, and the image of the protest in the broader public, in terms of popular topics, are modeled with an agent-based approach. We will use two distinct cases to inform the modeling process one in Iran and another in Germany.

The emergence of social protests has been captured with threshold models of collective behavior by Granovetter (1978) and Kuran (1989). Both models assume that every person has an individual threshold defining the minimal percentage of the protesting population that convinces the individual to join the protest. The rational-choice interpretation of this threshold is that this is the value where expected benefits exceed the expected costs of protest. In that sense, a low threshold stands for a person with strong concerns who is easily motivated to protest, while a person with a high threshold has few concerns. A reasonably simplifying first assumption, also used by Granovetter, is that thresholds are normally distributed with a certain mean value greater than zero. The persons with thresholds of zero or below are the initial protesters who can trigger others also to start to protest and so on until a final number of protestors is reached. For a normal distribution with a standard deviation below a critical value, only a small fraction ends up in protest, while the protest cascades to almost all people when the standard deviation is slightly above a critical value. Granovetter's model assumes that every person has the information about the global fraction of protesters.

Granovetter's and Kuran's model can explain how it comes that suddenly large protest movements emerge. They however do not take into account that individuals might not assess the fraction of protesting people in the whole population but only those in their immediate social networks. Watts (2002) applied the idea of Granovetter's threshold model to an undirected random network and showed that global cascades can be triggered by one protester while other protesters have equal thresholds (e.g., all 0.2) when the average number of links (i.e., association among protesters) is relatively low (between 1 and 6). The cascades, however, do not happen for denser networks. Dodds & Watts (2004) developed this model into a general model of contagion where individuals may receive several "doses" of motivating messages from others that sum up and trigger protesting when a threshold is exceeded. This model also includes compartmental models from epidemiology, such as the SI (susceptible-infectious) and SIR (susceptible-infectious-recovered) models, which are the canonical models for the spread of infectious diseases. In our model, we will use the threshold concept as well as the dose concept. We will assume that people can be activated to protest when a fraction of their social contacts is protesting. We will also assume that social media messages function as doses of concern with respect to particular topics for people who are not yet protesting.

Lohmann (1994) modifies the Granovetter and the Kuran model to focus on participation in a street protest as a costly political action that reveals information on how likely protesters deem political change. Klein & Marx (2018) pursue a similar idea but focus on explicit conversational information exchange between agents and asymmetric learning as a driving factor for the formation of mass movements. In their model, agents have a certain level of grievance and develop expectations of how likely political change is. When two agents meet randomly, one of them can access the other one's attitude. If asked, agents reveal their interest in change. However, since asking has a cost, only those critical of the system try to elicit their conversational partner's attitude. Hence, agents can learn from replies to questions that they ask themselves but also from others asking them or refraining from doing so. This results in asymmetric learning because agents who want change can learn from any interaction while supporters of the status quo only learn from interactions where their conversational partner and not they themselves are given a chance to ask. This means that genuine advocates of change deem change more likely than their peers who are content with the status quo. Moreover, the model shows that agents tend to underestimate the chance for change, while expectations are more accurate for societies with higher spatial or social mobility. Our model implements the idea that expression of one's concern is costly by implementing the possibility of agents sending unpolitical messages instead of expressing their concern. Furthermore, the above-mentioned possibility of social activation honors the fact that people decide whether to join a protest also based on information about the recent number of protesters.

Similarly, Epstein's (2002) model of decentralized rebellion is mainly built on activation but not only triggered by a high number of already activated agents in the neighborhood but also inhibited by repression through the presence of cops. Like the aforementioned models, Epstein's focus is also on fundamental rebellion and hence only captures concern with a single topic (i.e., the current general situation), thereby ignoring the possibility of multiple topics within a protest and agents influencing each other with regard to these topics.

In her investigation of the development of news cycles, Waldherr (2014) touches upon different topics gaining or losing attention within a group of interacting agents. In her model, however, agents are journalists and they are interested in topics rather than concerned about them; thus, attention for a topic has no external consequences like the formation of a protest.

Although our model builds on existing works on protest development as a question of costly choice, social exchange, and information retrieval, it goes beyond previous research by taking into account agents' genuine concern about multiple topics as well as their communicative exchanges on social media. In the following, we analyze two recent cases where protest dynamics and topical changes coevolve and use them to develop our agent-based model.

3.2 Data

To capture significant similarities and differences in the street protest phenomenon, we deliberately take data from two recent cases of protests from different cultures and political systems: The Iran protests in December 2017 and January 2018 exemplifies a short-term protest that heated up quickly and ended abruptly. In contrast, PEGIDA in Germany since 2014 is a case of long-term motivation of protesters and slow topic shift that can be considered as a social movement. A social movement is a sort of organization with specific goals (Della Porta & Diani 2009, p 145-150) while a single protest, like the Iran case may not have leaders or definite goals. Protests, in the long run, may turn into a social movement.

3.2.1 Iran Protest 2017/18

Our observations on this case stem from primary data analyses of videos and photographs taken at the street protests depicting protest slogans and Iranian online activity, mainly on Telegram, the most popular social media platform in Iran (MohammadReza Azali 2016), with regard to the protest.

On December 28, 2017, in Mashhad, capital of Khorasan Razavi province and the second largest city in the country after the capital city Tehran, a demonstration took place in the main square of the city by the invitation of some hardline fundamentalist/conservative political groups opposing the government of president Rohani. The organizers aimed to put pressure on the president by focusing on economic problems and showing how people are supporting the opposition. However, within hours after the protest started, organizers could not control the crowd and slogans radicalized to the critique of the whole political system. Videos from the demonstrations were shared online to millions of people, and consequently, unlike previous Iranian street movements, protests started in more than 100 cities all over Iran (Rahmani Fazli 2018), with the most intense protests occurring in smaller cities. However, only minor physical conflicts with authorities arose, and there was less systematic oppression by the police in comparison with previous protests, because the government tolerated the protests as the president recognized the protesters' right to express their concerns (Euronews 2018). Demonstrations and their repercussion on social media faded out a week after the first protest.

Albeit this short time frame, the protest experienced various shifts of focus visible in daily changes of protest slogans. Overall, we could identify nine different topics shown in Figure 3.1. We identified these nine topics by watching all protest videos posted in influencing Telegram channels (73 videos) during the seven days of the protests in more than 36 cities. In total, 78 different slogans were extracted from these videos. Then, we categorized them into nine topics. Figure 3.1 also shows in how many cities we found slogans from a given topic. Moreover, topics had different fates along the seven days of protest, as some had uniform popularity and others had more fluctuations in popularity.

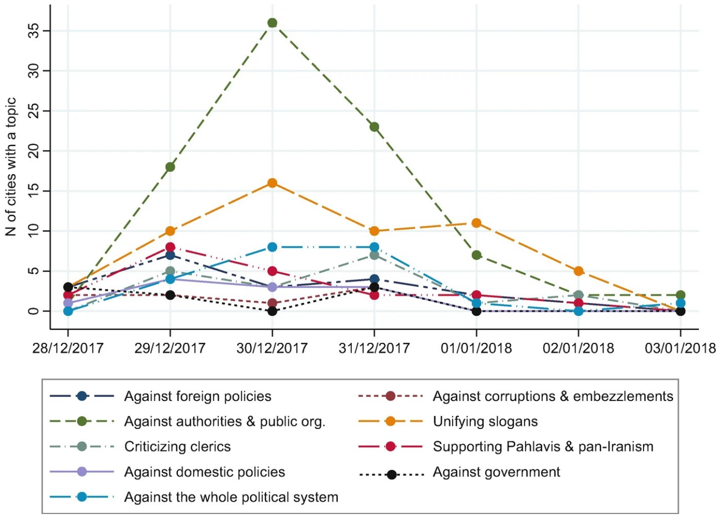

Figure 3.1: The number of cities with a topic of protest for the seven days of the protest in Iran

Figure 3.2 shows that different cities had a different number of topics on different days. This underlines the fact that there was not one dominant topic in the protest. This underpins that the movement was decentralized and spontaneous and hence subject to internal dynamics instead of being led by political players pursuing a specific agenda. For example, initial supporters condemned slogans against the whole political regime as some of them are strong defenders of it (Zand 2017). Most political camps in Iran were surprised by the daily developments and hence confined themselves to interpreting events in light of their own goals. This struggle for interpreting the protest was clearly reflected in the first page of political newspapers (Khedmati 2018).

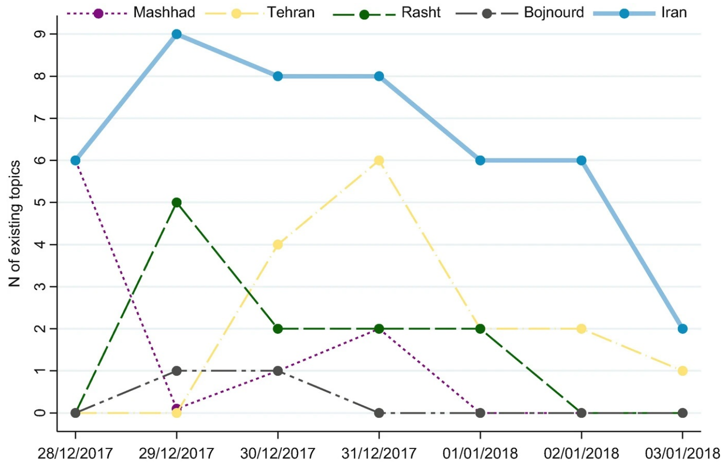

Figure 3.2: The number of popular topics in the whole country and four cities during the seven days of protest in Iran

Ordinary non-protesting citizens also interpreted and discussed the developments within families, with colleagues or friends in person and on social media (BBC 2018). Hence, albeit the fact that only about 0.1% of the population joined street protests directly (Rahmani Fazli 2018), a broad debate in society mirrored the protest topics and tensions between them not only during the protest but still a month after it.

We initially aimed to find the popularity of each protest topic on several social media channels, namely Instagram, Telegram, and Twitter, day by day. This could have shown how the street protest and online trends are interrelated and evolve mutually. But tools for analyzing social media turned out to be too expensive and not Persian-friendly enough.

Google Trends, as it is deployed by many scholars (e.g., Choi & Varian (2012); Mellon (2013, 2014); Minkus et al. (2019)) was an alternative for our goal. We searched for the popularity of street slogans on the web, which includes any kind of a text published on the internet (if Google indexes it). This can be a fine proxy of what was important for Iranians during the lifespan of the 2017/2018 protest. Each topic consists of some slogans in the reviewed videos that were gathered from influential Telegram channels. As Google Trends gives indices only for single words or terms, it was impossible to search trends with multiple slogans that constitute one topic. So we searched for single slogans in Iran in Google Trends. Out of 73 slogans, there were data for 10 in Google Trends. The existence of common trends between the number of protesting cities and the Google Trends index shows how hot debates on the internet and in the streets were associated.

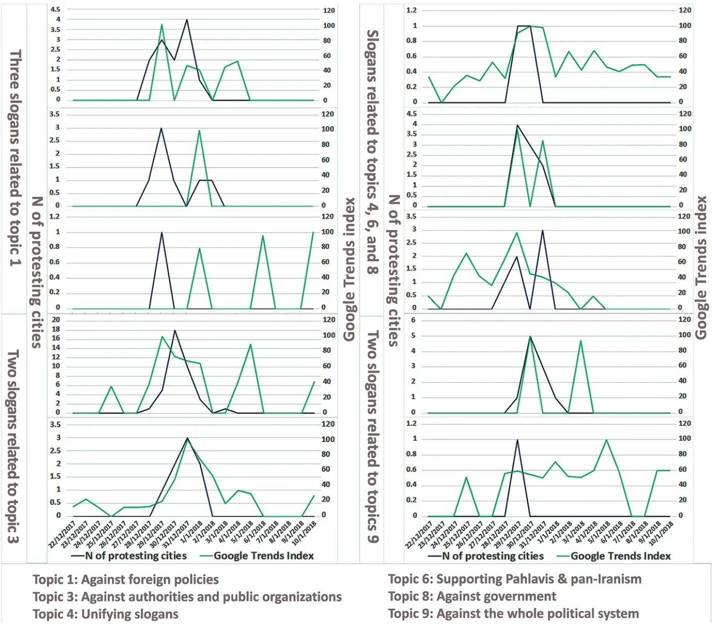

Figure 3.3: Examples for the number of protesting cities and Google Trends index during the lifespan of the 2017/2018 Iran protest

Figure 3.3 shows the different patterns of the positive relationship between 10 slogans on the internet and in the streets (in cross-correlation analyses, eight of them had positive relationships). In most cases, the climaxes of online and street topics are the same day or a little retarded or anticipated. It is thus plausible that online and street protests respond to each other. This means that street protests and debates on social media react to each other and can have mutual influence.

The Iran case is an example of protests that start fast and gather people with different topics of interest. In this case, the protest is well-connected to interactions among different actors on social media. Change in the popularity of topics in cities and the lateral change in Iranians' online concerns is considerable.

3.2.2 PEGIDA, Germany Since 2014 and Ongoing

The far right-wing populist movement "Patriotische Europäer Gegen die Islamisierung des Abendlandes" (Patriotic Europeans against the Islamisation of the Occident) or short PEGIDA was founded in closed social media groups without party affiliation (Vorländer et al. 2018, p 2). Soon, a public Facebook page was launched for communication with protesters and general political statements. The page was banned for violation of community standards but immediately re-established (Vorländer et al. 2018, p 23-27). Weekly street protests started in the city of Dresden in Saxony, Germany, and sparked protests in other German cities. On October 20, 2014, about 350 protesters joined the first PEGIDA street protest and expressed their worries about public demonstrations in support of different parties in the Syrian civil war and Islamic extremism. However, this developed into a rejection of Islam and Muslims in general over the next weeks. Moreover, PEGIDA criticized first the local Dresden refugee policy and later the German national one (Vorländer et al. 2016, p 5-7). Figure 3.4 shows that the number of supporters constantly rose and peaked at 25,000 on January 12, 2015 (Durchgezählt.org 2016). After that, the number of protesters decreased to 2000-3000 and PEGIDA organizers amended its topics by a general critique of the political establishment and also the traditional media. When the so-called refugee crisis in the EU arose in summer and autumn 2015, several hundred thousand refugees arrived in Germany and were sent to (often improvised) shelters across the country (Glorius et al. 2018, p 113). As a consequence, PEGIDA could then mobilize more people again. This resulted in a second peak of 15,000-20,000 protesters on October 19, 2015. After spring 2016 the figures declined again and remain at the level of about 2000 protesters until now (2019). These protesters still oppose migrants, traditional media, and the German political establishment.

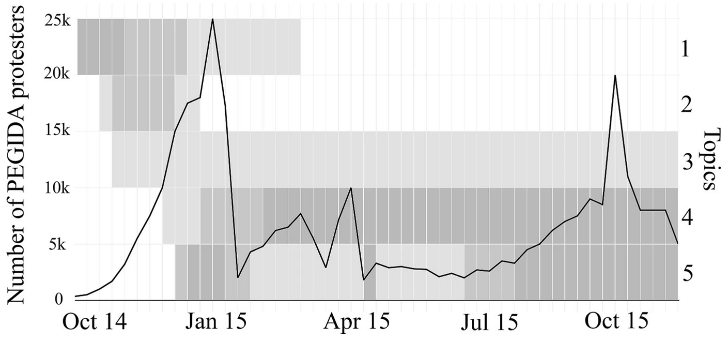

Figure 3.4: Number of PEGIDA protesters between October 20, 2014, and November 26, 2015 (Source: Durchgezählt.org (2016)) and tendencies in topics lobbied in the protest as found on the PEGIDA Facebook page and elaborated by Rucht et al. (2015) and Vorländer et al. (2016) based on social media communication, slogans at the protest and interviews conducted with protesters. Darker shades mean higher tentative prevalence of the respective topic: 1 = Fear of radical Islam; 2 = critique of Dresden local refugee policy; 3 = anti-feminist sentiment; 4 = fundamental criticism of political establishment and traditional media; 5 = general xenophobia/anti-refugee sentiment

During the protest peak time in December 2014 and January 2015, only few protesters interviewed or surveyed by different research teams (Vorländer et al. 2015; Rucht et al. 2015; Geiges et al. 2015) expressed particular issues with Islam, which at the time was the main message conveyed by PEGIDA organizers on banners at the protest or on social media. Instead, protest attendees were more concerned about refugee policy in general and felt alienated from the political establishment (which partially led to distrust in the political system altogether) and were unhappy with traditional media news coverage of political events.

Overall, PEGIDA in Germany exemplifies a type of protest that starts without connection to existing political actors and with no revolutionary ideas but focuses on a narrow topic; however, people who are generally dissatisfied join the protest and cause a shift of topics towards a more generalized critique of the political establishment. Furthermore, PEGIDA shows that protests can prevail with a small number of supporters and despite not reaching any of its goals directly impact the general political debate (Vorländer et al. 2018, p 26).

Finally, PEGIDA highlights the importance of understanding the interplay of street protests and their social media image as well as interactions of protest leaders and other political actors.

3.2.3 Stylized Data Facts

Although PEGIDA in Germany and the 2017/2018 protests in Iran seem very different at first glance, our analysis revealed common structural features that a model should capture.

In both cases, topics lobbied in the street shifted away from what organizers of the initial protests intended. This was also noted for the Arab spring by Hussain & Howard (2013) and for Occupy Wall Street in the USA and anti-austerity protests in Greece or Spain by Theocharis et al. (2015). One explanation for these shifts is that protesters have diverse ideas. A few of these ideas can grow more popular and dominate others over time. However, radical shifts do not only occur with regard to topics, but also the number of protesters can drastically increase or decrease either gradually or from one protest day to the next one.

While activity on the street is an important factor for publicity and acknowledgment of a protest, nowadays online space largely contributes to the success of a protest in two ways: Firstly, as spaces for debate, online social networks allow protesters to spread their ideas and develop them further (Lim 2012), as it can, for example, be observed on the PEGIDA Facebook page or in Telegram groups of Iranian protest supporters. Secondly, people can also practically coordinate upcoming street protests by, e.g., sharing information about the time and location, which PEGIDA frequently does prominently by utilizing its page profile and cover pictures for that purpose.

Overall, differences between street protests seem not to be of structural nature, but one should investigate reasons for these differences in specific circumstances of the protest and protesters. However, these specific circumstances can often not easily be empirically accessed, or one may want to predict the fate of future protests based on assumptions about the shape of the specific factors. Hence, our model helps to assess how different circumstances relate to different protest fates.

3.3 Agent-Based Model

We model the evolution of street protests in terms of individual concerns, social activation, topic selection, and increasing concerns through topic propagation in social media. We only model the activation of protesters and the buildup of concerns and not the dampening and die-out of protests. Before specifying the details, we describe the basic idea.

In our model, several individuals are interconnected in a social network. Each individual holds political concerns of different magnitudes on a finite set of topics. Individuals have different protest thresholds analog to Granovetter (1978). They begin to protest when at least one of their concerns is above the threshold. If this is not the case, they may also join the protest when the fraction of protesting others in their social contacts exceeds the threshold. Thus, individuals can protest because of concerns or because of social activation. The decision to do either is based on the same individual threshold. So, we assume that individuals with a low threshold are more susceptible to both types of activation. They will start to protest already with low concerns or with a low fraction of protesting others. An individual joining a protest decides on one of the topics to protest. A concerned protester selects one of the topics where the concern is above the threshold. Selection is probabilistic with probabilities proportional to concerns. A protester protesting because of social activation has no concern above the threshold and therefore selects a topic from all topics based on probabilities proportional to their concerns. Further on, all individuals, protesting or not, post a message in their social network. Individuals post if they joined a protest and with which topic. Individuals who did not protest post a message unrelated to the protest. The next day people with no concern above threshold read the messages in their social media news feed. Individuals with no concern above their threshold randomly pick one of the messages from their news feed. When this message is protest-related, they increase their concern on the topic of the message. This can be considered a dose of concern analog to Dodds & Watts (2004). People who follow mostly non-protesting others will receive mostly messages that are not protest-related and will thus likely not increase their concerns. This whole process repeats daily and can trigger different fates of protests with respect to the number of protesters and how prevalent the different topics are in the protest. We implemented this model in NetLogo (Wilensky 1999). The model is also provided for reference (Lorenz et al. 2019). It can be downloaded and run in NetLogo, which is free to use.

3.3.1 Agents, Follower Network, Thresholds, and Concerns

The agents in the model are individuals who are connected in a static directed social network built upon initialization. The network can be interpreted as a follower network where an agent can read the social media posts of the other agents following but not necessarily vice versa. The follower network is created in two parts. First, a directed preferential attachment network is built, representing links to potential "celebrities" at various magnitudes of fame. This is built by successively creating agents whereupon creation each follows a fixed number of other already existing agents (or all other agents for the very first agents), where agents are selected with probabilities proportional to the number of current followers (plus one to give the newest nodes a non-zero probability to become selected). Second, a friends' network is built. A friend-link is represented by reciprocal follower relations. The friends' network is a random network, where every possible link is created with a probability selected such that the expected number of friends is a certain integer.Footnote 1 That way, we mimic a typical network with mixed properties of social and information networks showing, for example, an in-degree (followers) distribution more skewed and fat-tailed than the out-degree (following) distribution (Myers et al. 2014).

As variables, each agent has a protest threshold which stays constant after initialization and a vector of concern values on a certain number of topics. The topics are the same for all agents; the concern values can change over time. Protest thresholds are real numbers. Any number larger than one represents an agent who will never join a protest for personal reasons but can impact others' decision to join. Any value of zero or less represents an agent who will always protest regardless of concern or protesting others. Concern values are integers, including zero but less or equal to a certain maximal concern. In a world with five topics, the concern vector [0 2 3 0 7] represents that the agent is most concerned about topic 5 and not at all concerned about topics 1 and 4. Two other dynamic variables of agents are the protest status, which is either "concern," "social," or "no," and their topic of protest on which they post a message in social media. The protest topic is zero if an agent is not protesting, or the topic (represented by the numerical label of the topic) they chose for the protest. As this is chosen randomly with probabilities proportional to concerns, this is usually a topic on which they have a high concern value. The topic of protest represents a protest-related social media post which can be read by followers. A topic of concern with the value zero represents a posting not related to protest.

3.3.2 Agents' Activities

In the full model, there are three protest mechanisms: the decision to protest because of concerns above threshold (concern protest), the increase of concern through information from social media (social media concern), and the decision to protest because of many others in the social network protest (social activation). These mechanisms can be independently switched on and off. In the following, we consider that all are switched on.

On each tick (we can think of a day) agents do the following activities.

1. All agents which are not already concerned enough to protest read their news feed and compute the fraction of the people they follow who protested. The news feed represents the list of social media messages from the last day an agent reads. In the model, it is a list of the topics of protest and non-protest-related messages of all agents the agent follows. From the news feed, the agent also extracts the fraction of protesting people.

2. All agents decide if they join the protest.

   2.1 (Concern protest) An agent checks if a concern on at least one topic is greater than the individual protest threshold times the maximally possible concern value (a global parameter set to ten in the following). If this is the case, the agent sets the protest status to "concern."Footnote 2 We refer to this condition as "concern above the threshold." An agent with protest status "concern" then selects the topic of concern from all the topics that are above the threshold randomly with probabilities proportional to concern values.

2.2 (Social media concern) Agents without concerns above the threshold will read their news feeds and select one topic of concern from this list at random. This can well be zero, representing a message which is not protest-related. In this case, nothing more happens. If it is a protest topic, the agent will increase the concern value on that topic by one. Note that, agents with a concern above the threshold will not increase any concerns anymore, because we assume that an agent only needs one concern above the threshold to join, and we are only modeling the buildup of one particular protest.

2.3 (Social activation) Agents without concerns above the threshold check if the fraction of people followed who protest is greater than the threshold. If this is the case, the agent is socially activated and sets the protest status to "social" otherwise to "no." If the agent protests, one of the topics is selected for the protest at random with probabilities proportional to the concern values. This selection happens even though the concerns themselves are all not above the threshold. The rationale is that for joining a protest, even when only socially activated, one needs a topic of concern.

3.3.3 Initial Conditions and Stopping Rules

The initialization of a simulation run (setup procedure) is done as follows. First, a fixed number of agents is created. Then, directed links are created using the preferential attachment generator and, as described above, further reciprocal friends' links are created in a random network. Network generation is steered by the parameters following and friends, which describe the desired average number of directed and reciprocal links an agent should have. Agents' static protest thresholds are random numbers from a normal distribution with mean threshold level and standard deviation threshold-dispersion. Agents' dynamic concern vectors are topic-num integers between zero and max-concern. The concern value on each topic is initialized as a binomial random number with probability initial-concern-level. This implies that the expected concern on each topic for each agent is initial-concern-level times max-concern. The three mechanisms of concern protest (CP), social-media-concern (SMC), and social activation (SA) described above can all be independently switched "on" and "off." All "on" specifies the full model.

It turns out that only the five combinations of CP, SA, CP-SA, CP-SMC, and CP-SMC-SA are sensible configurations to distinguish. Just SMC will never spark anyone to protest, and SMC-SA would fully coincide with SA with respect to the protest status of agents. A logical analysis of all model variants shows that an agent can only experience three types of transitions of the protest status: "no" → "concern", "no" → "social", and "social" → "concern". Therefore, the total number of protesters (genuinely concerned or socially activated) can only increase or stay constant. As already mentioned, the decline of protests was deliberately not the aim of the modeling.

Only when social media concern is switched on, the concerns of agents can increase. Thus, it is easy to see that in the CP regime the total number of protesters is reached after one time-step, and in the SA and CP-SA regime, the total number of protesters is reached when the number of protesters stays constant for one time-step. The chosen protest topics may change but the distribution for the probabilistic selection stays constant.

When social media concern is switched on, every agent who is at some point following a protesting agent will successively increase the concern on at least one topic in the long run. Consequently, the agent will turn into a concerned protester unless the agent has a protest threshold above one, which rules out any protest. Thus, in most configurations with social media concern, all agents with thresholds below one end up with protest status "concern." Furthermore, the concerns of agents remain stable once they are concerned protesters. Therefore, also the distribution for the random selection of topics of concern in the whole society stabilizes once all protesters turn to be concerned protesters. We use these insights to define the stopping rules for simulation runs.

3.4 Simulation Experiment

In our model exploration, we used always the same network generation parameters. We assume that each agent follows five others (directed links in a preferential attachment network) and has five friends (undirected links in a random network). Furthermore, the maximum possible concern is fixed at ten. First, we work with distinct values of the threshold level, initial concern, and threshold-dispersion to represent the cases of Iran and Germany. Afterward, we explore the whole space of the three parameters to gain general insights on the model mechanics that help understand other protests as well as possible future developments in our two example cases. When interpreting the simulation outcome, one should bear in mind that the total population in the model does not necessarily represent everyone in society but is conceptually limited to those active people linked to the protest on social media as well as generally sympathetic about the protest and any of its topics. Moreover, the time-frame is different for different protests based on how dynamical they are.

3.4.1 The Iran Case in the Model

The empirical observation of the Iran case (see Sect. 2.1) can be translated to nine topics and a low initial-concern-level (0.1), which should mirror the fact that protests broke out suddenly and was not connected to one rising specific concern. The medium threshold level of 0.5 represents the fact that people generally had a sense of urgency and willingness to express their views but at the same time, they would not campaign on the streets lightheartedly. Since the Iran protest evolved dynamically, one should understand a time-step in the model as a few hours in reality, while the population consists of all citizens who consider street protests an appropriate and efficient way of expressing their political opinion, regardless of their political stripe.

Figure 3.5 depicts a simulation run, exploiting such parameter values. It compares snapshots of the model world to the overall development of the number of protesters and prevalence of topics in the protest. In the model world, non-protesting agents are black, while protesting agents have the color of their protest topic shaded by their concern value on that topic. Agents with protest status “concern” are filled dots, while the protest status “social” is indicated as white-filled circles. Agents are arranged according to the structure in their preference attachment (follower) network, and an agent’s size indicates its centrality in that network.

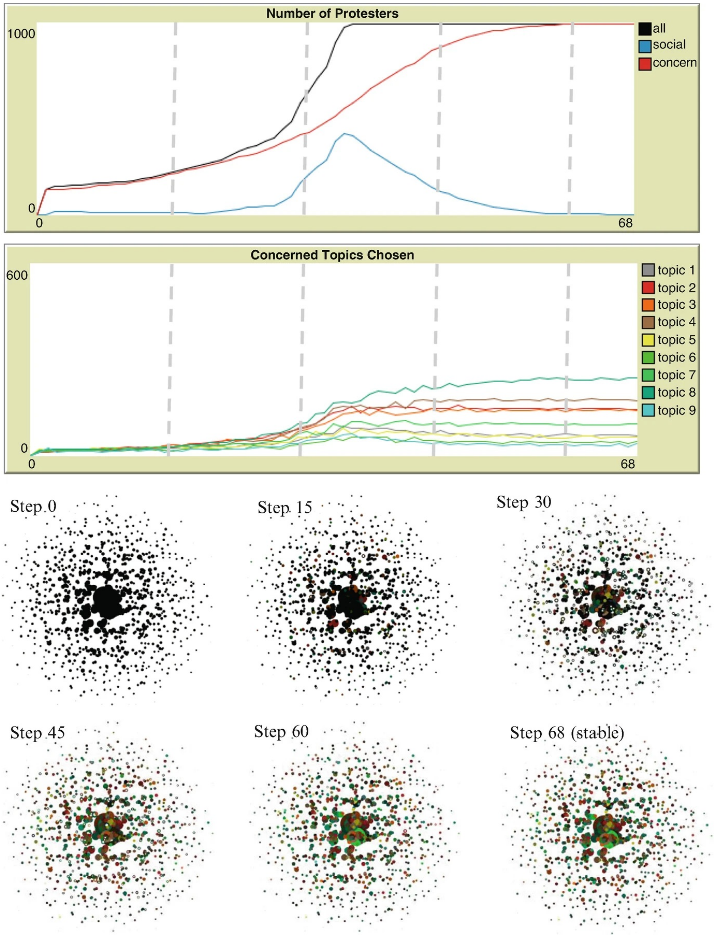

Figure 3.5: Simulation run of the Iran case (parameter setting cf. Table 1)

Figure 3.5 shows that initially, only a few people protest, but numbers steadily increase quickly. The social dimension of the protest is most important after it has gained considerable concern-driven support (starting at step 27); at this point, some people would not yet have joined the protest out of concern but they do join because of social activation. This is crucial here because running the setting without social activation witnesses the protest dying out. However, social activation does not mean that people are not concerned at all and only join because they want to meet their friends on the street. Instead, the presence of people they know may raise one's faith in the protest's success or even a sense of safety when protesting, as Klein & Marx (2018) suggest. Once the protest has consolidated in numbers of protesters, the socially motivated ones also become genuinely concerned (starting from step 36). There are constant minor fluctuations between topics showing that many people are concerned about more than one topic and that slogans in the protest often depend on up-to-the-minute news. This amounts to a different focus of protesters in different clusters within the network (comparable to different cities in Iran—not visible in the figure) and at different times.

3.4.2 The Germany Case in the Model

Representing PEGIDA in the model works with five topics and the same initial-concern-level (0.1) as in the Iran case above but with a higher threshold level of 0.7. This higher threshold represents the fact that issues of the PEGIDA movement are more confined to a single topic area and also less severe for people's everyday lives: In order to lobby a topic in the street protest, an actor has to perceive issues with respect to that topic as particularly severe. One time-step in the model can be identified with one day of the PEGIDA protest, which evolved more slowly than the Iran case. The population also does not represent the whole political landscape in Germany but includes only those possible protesters who sympathize with right-wing ideas or are deeply disappointed with the political and social establishment.

In Figure 3.6, one can see one possible situation of how a protest given these input parameters can unfold. The movement takes about 50 steps of only a few people protesting, which corresponds to smaller actions taken by PEGIDA organizers and core supporters prior to focusing on PEGIDA itself. However, after that initial phase, people join quickly and they mostly do that because of genuine concern, which they build up in the meantime, not because of social activation. That again is in line with the empirical findings showing that despite organizers' appeal to moderate views, protesters expressed genuine right-wing sentiment (Vorländer et al. 2018, p 64-66). Initially, a variety of topics is present within the protest and one of them temporarily becomes the most important one (in reality it was "anti-refugee"). However, later (at step 70) a second topic (in reality it was "critique of the political establishment") emerges and most protesters now (at step 99) regard this as their primary concern. That protesters become part of the same filter bubble (online and offline) also contributes to the focus on a single protest topic. Nevertheless, the first topic still maintains considerable support and is simply outnumbered by new protesters supporting the new one. While social activation has a smaller influence than in the Iran case simulation on the number of protesters, it is the main facilitator for the second topic overtaking the first topic. Additional simulations with the same realization of random events but without social activation show that the overtaking phenomenon does not occur in the case when social activation is turned off. In reality, PEGIDA organizers frequently encouraged protesters to actively reach out to their friends (Rucht et al. 2015, p 17-18) and while these friends may not have shared a strong anti-refugee sentiment, they held a generally critical opinion of the government and joined for this reason (Rucht et al. 2015, p 28-51).

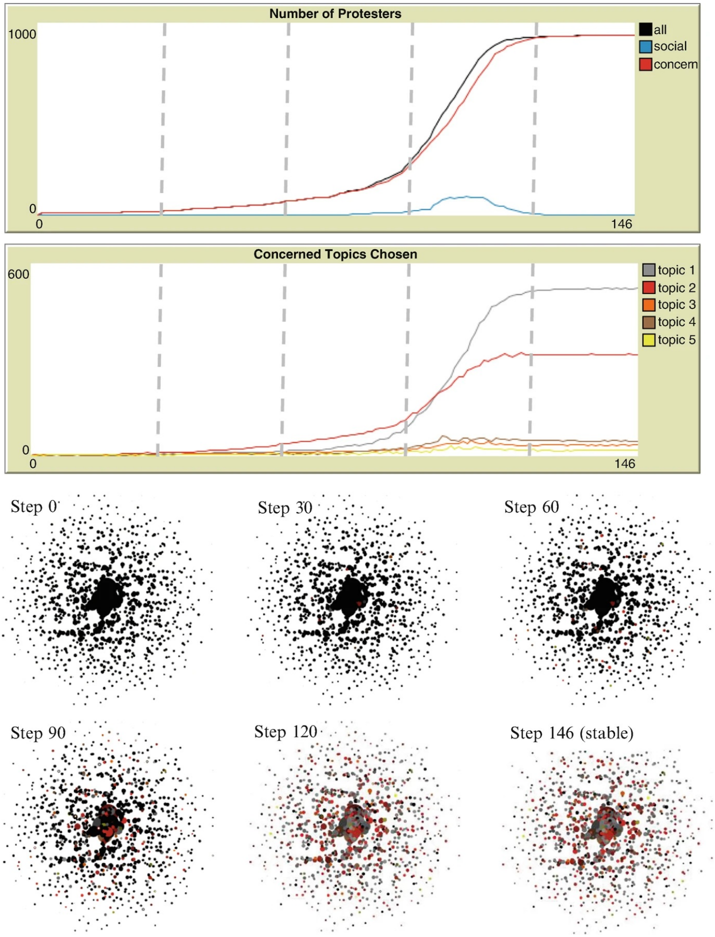

Figure 3.6: Simulation run of the Germany case (parameter setting cf. Table 1)

3.4.3 Comparison Between the Iran and Germany Model Simulations

The parameter values for the simulations for the two cases are summarized in Table 1. The similarity of parameter values for the Iran and Germany cases indicates that they are structurally related. The cases differ in the perceived overall importance of the protest cause which translates to a lower threshold level in the model of the Iran case. They also differ in the number of potential protest topics (fewer in Germany). Furthermore, while the specific features of the empirical cases (multiplicity of topics for Iran; single important topic and the crucial role of social activation for Germany) are common for the corresponding parameter values, the effects are not guaranteed to occur under a given setting. That is the case because case-specific features like the layout in the random friendship network or the individual properties of central hubs in the preferential attachment network play an important role in the simulation outcome, too. Such aspects are specific features of a society (Vaisey & Lizardo 2010); the present model suggests that these case-dependent societal aspects can explain why seemingly similar protests experience different fates in empirical cases.

Parameter	**Iran case**	**Germany case**
Population	1000	1000
Following	5	5
Friends	5	5
Num-topics	9	5
Max-concern	10	10
Initial-concern-level	0.1	0.1
Threshold level	0.5	0.7
Threshold-dispersion	0.2	0.2
RandomSeed	16	17

Table 3.1: The randomSeed specifies the sequence of random events used in the NetLogo model (Lorenz et al. 2019)

3.4.4 Parameter Study

In the following, we analyze how the final number of protesters and the distribution of protest topics depend on the three protest mechanisms as well as the threshold level and the initial-concern-level in the society. To that end, we made several simulation runs using NetLogo's BehaviorSpace (Lorenz et al. 2019), setting all other parameters to the Iran case from Table 1. For an initial-concern-level of 0.1, we vary the threshold level from 0 to 0.8 in steps of 0.05. Furthermore, we also vary the initial-concern-level in steps of 0.05 from 0 to 0.5, for a threshold level of 0.5. We either run the simulation until a natural stopping criterion is reached (cf. Sect. 3.3) or stop it after 1000 time-steps. This ensured that we have reached a final configuration where the number of protesters and the concerns do not change anymore. What remains are stochastic changes in the protest topics selected, because agents may have several topics above the threshold. We computed fifty simulation runs for each configuration using no prespecified random seeds. Based on how often each topic is selected for protest, one can compute an effective number of topics $\frac{1}{\sum p_i^2}$ where the summation is over all topics and p_i is the number of agents protesting for topic i divided by the total number of protesting agents. This number is analog to the effective number of parties of Laakso & Taagepera (1979).

Figure 3.7 shows the results. Dots show data points for individual simulation runs. Lines show the mean value over all simulation runs for this parameter setting.

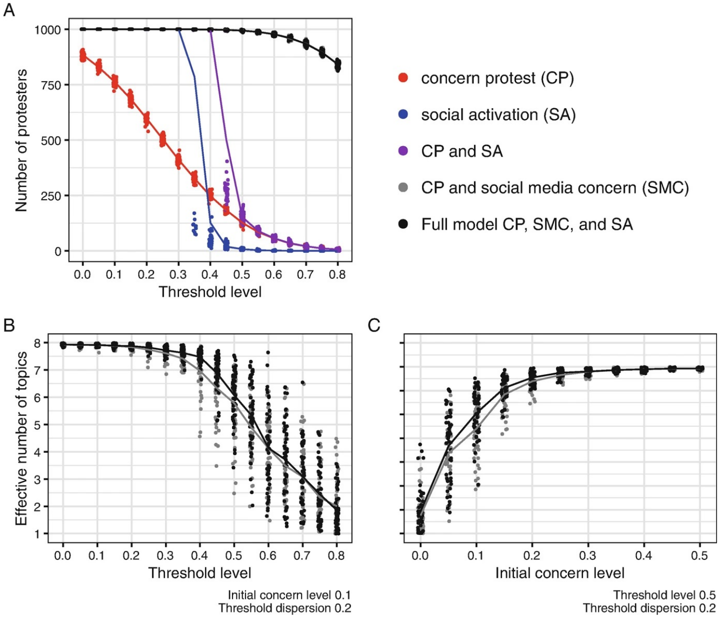

Figure 3.7: Results for the parameter study. The threshold level is the mean of the individual thresholds. Note, that the gray dots for "CP and social media concern (SMC)" configuration in Panel A are mostly covered by black dots

Panel A shows the number of final protesters with respect to the threshold level. With only concern protest, the number of protesters smoothly declines with a rising threshold level. This is simply explained by initial conditions. With social activation, we have a threshold regime: At a critical threshold level of about 0.35, regimes change from a full protest to almost no protesters. This is similar to Granovetter (1978) and Watts (2002). We have a mixed model with a network as Watts and heterogeneous thresholds as Granovetter. This critical threshold is shifted slightly upwards when concern protest and social activation are combined. When social media concern is added, protest builds up, sometimes quite slowly, until usually all individuals with thresholds below one protest. This is independent of the mechanism of social activation being on or off. For relatively high threshold levels, there is a sizable amount of such individuals who never protest.

Panel B shows the effective number of topics for the same setup. This is only of interest when social media concern is involved. In other cases, without social media, no particular structure of topics evolves. This implies an effective number of topics around eight. An effective number of nine would only occur with perfect equality of all topics. Random fluctuation brings the number to about eight. The same happens with social media when the threshold level is relatively low but changes with higher threshold levels. With threshold levels around 0.5, a hierarchy of topics evolves with an effective number of topics around 5. With even higher threshold levels, this reduces too much lower numbers of effective topics around 2. This essentially means that one topic dominates while others only play a minor or no role.

Panel C finally shows how the effective number of topics changes with increasing initial concerns for a fixed threshold level of 0.5. Panels B and C together show that a larger distance between threshold level and initial concern implies a lower number of effective topics. Only in these cases, social media has time to build a hierarchy of topics before an overall protest emerges. The combination of concern protest and social media with social activation implies a slightly higher number of effective topics. This happens due to the fact that socially activated actors bring new topics to the protest.

3.5 Discussion

The basic model version introduced in this paper can reproduce different empirically observed fates of protests and describe mechanisms that possibly cause these fates. We were able to show which individual protesters' properties were necessary to get the patterns empirically observed in the Iran and Germany case studies. Combining empirical studies of processes and understanding their possible causes in the model thereby is a key to understand how the relation of individual decisions and exchange online leads to street protests. The die-out of protest, however, was not part of this study.

The parameters explicitly modified in our model only provide necessary conditions for a certain protest fate. Specific features of the society in which the protest takes place are important for its fate too. In the model, these features are the network layouts and especially the positions of agents with certain concern levels on certain topics within the networks. Moreover, this model version is deliberately kept simple and hence cannot capture other aspects of social media interactions and street protests in reality. In an extended model, the protest could be given a more active role in the sense of introducing interaction among protesters in the streets leading to additional concern change or additional messages sent from the protest or individual protesters to the social network. The decision of whether or not to join a protest may need revision to capture real actors' decisions more closely. Finally, one may consider including external influences that, at a pre-defined simulation step or when certain conditions are met, lead to an exceptional emotional dampening for some or all agents regarding a specific topic or across all topics. For example, government reactions, such as suppression or policy change, are not included yet.

References

Anstead, N. & O'Loughlin, B. (2014). Social media analysis and public opinion: The 2010 UK general election. *Journal of Computer-Mediated Communication*, *20*. doi:10.1111/jcc4.12102
URL `http://dx.doi.org/10.1111/jcc4.12102`

Ayres, J. M. (1999). From the streets to the Internet: The cyber-diffusion of contention. *The Annals of the American Academy of Political and Social Science*, *566*. doi:10.1177/000271629956600111
URL `http://dx.doi.org/10.1177/000271629956600111`

BBC (2018). Iran protests: Social media messaging battle rages. (January 7)
URL `https://www.bbc.com/news/world-middle-east-42566083`

Choi, H. & Varian, H. (2012). Predicting the present with Google Trends. *Economic Record*, *88*. doi:10.1111/j.1475-4932.2012.00809.x
URL `http://dx.doi.org/10.1111/j.1475-4932.2012.00809.x`

Count Love (2019). Search. Retrieved June 16, 2019
URL `https://countlove.org/statistics.html`

Della Porta, D. & Diani, M. (2009). *Social movements: An introduction.* New York: Sons

DeLuca, K. M., Lawson, S. & Sun, Y. (2012). Occupy Wall Street on the public screens of social media: The many framings of the birth of a protest movement. *Communication, Culture & Critique*, *5*. doi:10.1111/j.1753-9137.2012.01141.x
URL http://dx.doi.org/10.1111/j.1753-9137.2012.01141.x

Dodds, P. & Watts, D. (2004). Universal behavior in a generalized model of contagion. *Physical Review Letters*, *92*. doi:10.1103/PhysRevLett.92.218701
URL http://dx.doi.org/10.1103/PhysRevLett.92.218701

Durchgezählt.org (2016). Statistik zu Pegida in Dresden)
URL https://durchgezaehlt.org/pegida-dresden-statistik/

Elson, S. B., Yeung, D., Roshan, P., Bohandy, S. R. & Nader, A. (2012). *Using social media to gauge Iranian public opinion and mood after the 2009 election*. Santa Monica, CA: Rand Corporation

Epstein, J. M. (2002). Modeling civil violence: An agent-based computational approach. *Proceedings of the National Academy of Sciences of the United States of America*, *99*. doi:10.1073/pnas.092080199
URL http://dx.doi.org/10.1073/pnas.092080199

Euronews (2018). Protests in Iran finished in favor of Rohani. (January 17)
URL https://fa.euronews.com/2018/01/17/

Geiges, L., Marg, S. & Walter, F. (2015). *Pegida: die schmutzige Seite der Zivilgesellschaft?* Bielefeld: transcript Verlag

Gerbaudo, P. (2012). *Tweets and the streets: Social media and contemporary activism*. London: Pluto Press

Glorius, B., Schondelmayer, A. C. & Dörfel, R. (2018). “Wandel durch Annäherung”? Gesellschaftliche Konflikte im Kontext der Flüchtlingsunterbringung im ländlichen Sachsen. In S. Goebel, T. Fischer, S. Kießling & A. Treiber (Eds.), *FluchtMigration und gesellschaftliche Transformationsprozesse*. Wiesbaden: Springer VS.

González-Bailón, S., Borge-Holthoefer, J. & Moreno, Y. (2013). Broadcasters and hidden influentials in online protest diffusion. *American Behavioral Scientist*, *57*. doi:10.1177/0002764213479371
URL http://dx.doi.org/10.1177/0002764213479371

González-Bailón, S., Borge-Holthoefer, J., Rivero, A. & Moreno, Y. (2011). The dynamics of protest recruitment through an online network. *Scientific Reports*, *1*. doi:10.1038/srep00197
URL http://dx.doi.org/10.1038/srep00197

Granovetter, M. (1978). Threshold models of collective behavior. *American Journal of Sociology*, *83*. doi:10.1086/226707
URL http://dx.doi.org/10.1086/226707

Howard, P. N., Duffy, A., Freelon, D., Hussain, M. M., Mari, W. & Maziad, M. (2011). Opening closed regimes: what was the role of social media during the Arab Spring? *SSRN Electronic Journal*. doi:10.2139/ssrn.2595096
URL http://dx.doi.org/10.2139/ssrn.2595096

Hussain, M. M. & Howard, P. N. (2013). What best explains successful protest cascades? ICTs and the fuzzy causes of the Arab Spring. *International Studies Review*, *15*. doi:10.1111/misr.12020
URL http://dx.doi.org/10.1111/misr.12020

Khedmati, M. (2018). What did Newspapers do in "Day protests"?

Klein, D. & Marx, J. (2018). Wenn Du gehst, geh ich auch! Die Rolle von Informationskaskaden bei der Entstehung von Massenbewegungen. *PVS Politische Vierteljahresschrift*, *58*. doi:10.5771/0032-3470-2017-4-560
URL http://dx.doi.org/10.5771/0032-3470-2017-4-560

Kuran, T. (1989). Sparks and prairie fires: A theory of unanticipated political revolution. *Public Choice*, *61*. doi:10.1007/BF00116762
URL http://dx.doi.org/10.1007/BF00116762

Laakso, M. & Taagepera, R. (1979). "Effective" number of parties. *Comparative Political Studies*, *12*. doi:10.1177/001041407901200101
URL http://dx.doi.org/10.1177/001041407901200101

Lankina, T. V. (2014). Daring to protest: When, why, and how Russia's citizens engage in street protest.

Lim, M. (2012). Clicks, cabs, and coffee houses: Social media and oppositional movements in Egypt, 2004–2011. *Journal of Communication*, *62*. doi:10.1111/j.1460-2466.2012.01628.x
URL http://dx.doi.org/10.1111/j.1460-2466.2012.01628.x

Lohmann, S. (1994). The dynamics of informational cascades: The Monday demonstrations in Leipzig, East Germany, 1989–91. *World Politics*, *47*. doi:10.2307/2950679
URL http://dx.doi.org/10.2307/2950679

Lorenz, J., Asgharpourmasouleh, A., Fattahzadeh, M. & Mayerhoffer, D. (2019). Model ProtestFate: Published Version (Version v1.0). doi:10.5281/zenodo.3243818
URL http://dx.doi.org/10.5281/zenodo.3243818

Mellon, J. (2013). Where and when can we use Google Trends to measure issue salience? *PS: Political Science & Politics*, *46*

Mellon, J. (2014). Internet search data and issue salience: The properties of Google Trends as a measure of issue salience. *Journal of Elections, Public Opinion & Parties*, *24*. doi:10.1080/17457289.2013.846346
URL http://dx.doi.org/10.1080/17457289.2013.846346

Minkus, L., Deutschmann, E. & Delhey, J. (2019). A Trump effect on the EU's popularity? The US Presidential Election as a Natural Experiment. *Perspectives on Politics*, *17*. doi:10.1017/S1537592718003262
URL http://dx.doi.org/10.1017/S1537592718003262

MohammadReza Azali, A. (2016). Infographic: Social Media Demographics in Iran
URL http://techrasa.com/2016/08/26/infographic-social-media-iran/

Myers, S. A., Sharma, A., Gupta, P. & Lin, J. (2014). *Information network or social network?* New York: ACM Press

Neumayer, C. & Stald, G. (2014). The mobile phone in street protest: Texting, tweeting, tracking, and tracing. *Mobile Media & Communication*, *2*. doi:10.1177/2050157913513255
URL http://dx.doi.org/10.1177/2050157913513255

Penney, J. & Dadas, C. (2014). (Re) Tweeting in the service of protest: Digital composition and circulation in the Occupy Wall Street movement. *New Media & Society*, *16*. doi:10.1177/1461444813479593
URL http://dx.doi.org/10.1177/1461444813479593

Qi, H., Manrique, P., Johnson, D., Restrepo, E. & Johnson, N. F. (2016). Open source data reveals connection between online and on-street protest activity. *EPJ Data Science*, *5*. doi:10.1140/epjds/s13688-016-0081-5
URL http://dx.doi.org/10.1140/epjds/s13688-016-0081-5

Rahmani Fazli, A. (2018). Untolds of Minister of State on the Day Protest. Interview with Alef (December 16)
URL https://www.alef.ir/news/3961220074.html

Rucht, P., Dieter andDaphi, Kocyba, P., Neuber, M., Roose, J., Scholl, F., Sommer, M., Stuppert, W. & Zajak, S. (2015). Protestforschung am Limit. Eine soziologische Annäherung an Pegida. *ipb working paper*

Shirky, C. (2011). The political power of social media: Technology, the public sphere, and political change. *Foreign Affairs*, *90*

Theocharis, Y., Lowe, W., Deth, J. W. & García-Albacete, G. (2015). Using Twitter to mobilize protest action: online mobilization patterns and action repertoires in the Occupy Wall Street, Indignados, and Aganaktismenoi movements. *Information, Communication & Society*, *18*. doi:10.1080/1369118X.2014.948035
URL `http://dx.doi.org/10.1080/1369118X.2014.948035`

Vaisey, S. & Lizardo, O. (2010). Can cultural worldviews influence network composition? *Social Forces*, *88*. doi:10.1353/sof.2010.0009
URL `http://dx.doi.org/10.1353/sof.2010.0009`

Valenzuela, S., Arriagada, A. & Scherman, A. (2012). The social media basis of youth protest behavior: The case of Chile. *Journal of Communication*, *62*. doi:10.1111/j.1460-2466.2012.01635.x
URL `http://dx.doi.org/10.1111/j.1460-2466.2012.01635.x`

Vorländer, H., Herold, M. & Schäller, S. (2015). *Wer geht zu PEGIDA und warum? Eine empirische Untersuchung von PEGIDA-Demonstranten in Dresden. Schriften zur Verfassungs-und Demokratieforschung.* Dresden: Zentrum für Verfassungs-und Demokratieforschung

Vorländer, H., Herold, M. & Schäller, S. (2016). *PEGIDA: Entwicklung, Zusammensetzung und Deutung einer Empörungsbewegung.* Wiesbaden: Springer-Verlag. doi:10.1007/978-3-658-10982-0
URL `http://dx.doi.org/10.1007/978-3-658-10982-0`

Vorländer, H., Herold, M. & Schäller, S. (2018). *PEGIDA and new right-wing populism in Germany.* Basingstoke: Palgrave Macmillan. doi:10.1007/978-3-319-67495-7
URL `http://dx.doi.org/10.1007/978-3-319-67495-7`

Waldherr, A. (2014). Emergence of news waves: A social simulation approach. *Journal of Communication*, *64*. doi:10.1111/jcom.12117
URL `http://dx.doi.org/10.1111/jcom.12117`

Watts, D. (2002). A simple model of global cascades on random networks. *Proceedings of the National Academy of Sciences of the United States of America*, *99*. doi:10.1073/pnas.082090499
URL `http://dx.doi.org/10.1073/pnas.082090499`

Wilensky, U. (1999). Center for connected learning and computer-based modeling. In *NetLogo*. Northwestern University

Zand, S. (2017). How the protests of "no to inflation" started? (December 30)
URL `https://fararu.com/fa/news`

4

Raising Children to Be (In-)Tolerant. Influence of Church, Education, and Society on Adolescents' Stance Towards Queer People in Germany.

Mayerhoffer, D.M. (2018). Raising Children to Be (In-)Tolerant: Influence of Church, Education, and Society on Adolescents' Stance towards Queer People in Germany. *Historical Social Research*, 43(1), 144-167.
https://nbn-resolving.org/urn:nbn:de:0168-ssoar-56449-9

The author thanks (in alphabetical order) Corinna Elsenbroich, Lasse Gerrits, Nigel Gilbert, Bettina Gregg, Dominik Klein and Johannes Marx for constructive criticism of the manuscript; the research was supported by the German Academic Exchange Service (DAAD), grant no. 57207042.

Abstract

There is a highly emotional debate in Germany regarding what to teach children about sexual plurality; different actors accuse each other of wrongful indoctrination. This paper presents a computational model based on the results of the SINUS youth study 2016 indicating that the dynamics of adolescents finding their own stance towards sexual plurality are fairly resilient towards external pressure by clerical or government activities. Instead, civil society plays a strong role in the process of children developing their own opinions. This underlines that values in society can reproduce intergenerationally.

Keywords Agent-Based Modelling, Social Values, Adolescents, Sexual Plurality, Church

Contents of this Paper

4.1 Introduction

In 2014, the green-red government of Baden-Wuerttemberg, Germany, planned introducing a new education agenda meant to raise awareness for sexual plurality (among other purposes). Pupils should implicitly encounter the topic during lessons in all subjects (e.g. by occasionally including trans- instead of cisgender in mathematical text problems) and thereby be encouraged to reflect on it. This was heavily opposed by Christian Conservatives and Christian fundamentalists because they suspected such approaches to be a promotion of LGBTQ[1]

lifestyle or at least presenting something as normal and acceptable which they considered merely a deviation from the norm. The opponents of the new

[1] **L**esbian, **G**ay, **B**isexual, **T**ransgender **Q**ueer. This paper uses *LGBTQ, queer* and *sexual plurality* as synonyms to describe any deviances from the norm of romantic relationships being constituted by one cisgender (identification with one‘s sex assigned at birth) male and one cisgender female. The study investigates adolescents‘ stances towards queerness understood that way. Colloquially, queer often includes allies (heterosexual cisgender men or women not living in an open or polyamorous relationship. However, being an ally describes acting upon a positive stance towards other queer people and since the aim of the research presented here is to evaluate the development of the stance itself, including allies in the term would cause circularity.

education agenda feared an indoctrination of adolescents to become more excessively open towards sexual plurality (Tagesspiegel 2014). Their resistance was successful: the government froze its plans for the new education agenda and later altered it to grant sexual plurality less room and importance (Kultusministerium 2016). This seems to prove complaints by some promoters of sexual plurality that the church is an institution which undermines and marginalises interests of LGBTQ people. They suspect Christian moralistic values transported by the institutional church through different channels in education (e.g. religious education lessons) to hinder children from developing their own, open stance towards sexual plurality (Queer.de 2015). That view of religion as a reason for being critical of LGBTQ people seems intuitive and scholars using different methodological approaches back up this intuition empirically, as Bhugra (1987) and Ahmad & Bhugra (2010) point out in their literature reviews.

Furthermore, both parties in the debate stress that education could be used to severely and deliberately influence adolescents‘ opinions concerning LGBTQ people. Since Plato (The Republic, 456-458), education plays a major role for many regimes of all political colour to introduce and sometimes indoctrinate their values to children. Such indoctrination did not only happen at school but also via youth groups and other leisure activities. Modern Democracies like Germany claim to teach a plurality of values and stay (relatively) neutral as a state. However, it seems understandable for those who view plurality as distinct from neutrality and as a doctrine itself to fear an “indoctrination of plurality”, given the history of education impacting children‘s value systems.

Despite the impact of formal education agendas, children develop their values in via communications with their social environment is for her development. This environment consists of an adolescent‘s family members but also of teachers and guides in youth groups and it passes latent values to her that are present in a society or its sub-groups. Changing those latent values is not as easy for state or church as altering an education agenda. But especially in puberty, many adolescents seem not to care about adults much and instead develop their values in exchanges with peers who come with a different perspective depending on their background. Overall, one should expect children‘s views of queer people to depend on society as a whole but also on deliberate interventions by actors like church or state.

This paper tests that expectation and investigates how openness towards sexual plurality of German teenagers develops between their 14th and 18th birthday with a special focus on influences by church and education. To capture that development a computational model is developed based on the SINUS youth study 2016. This study employs a mix of quantitative and qualitative methods to categorise children aged 14 to 17 by their attitudes as well as their living conditions into seven distinct milieus and describes properties of these milieus in depth. Section 4.2 introduces the model and data used to develop it. The most important results from simulating the model are presented in Section 4.3 and Section 4.4 discusses them

4.2 Introduction to the Model

4.2.1 Model Description

The model simulates the changing attitudes towards LGBTQ people of adolescents in all seven SINUS milieus[2] . For that purpose, a population of 2500 agents as teenagers of similar age is introduced. The simulation is assumed to start when they become 14 years old and runs until their 18th birthday in 48 steps, whereby each step represents one month. The population can be understood as the children of a small town or a district of a bigger city. However, the model landscape constitutes no representation of a physical space but instead agents‘ movement and encounters are a proxy for their communication. Each agent is part of a group representing a milieu from the SINUS study and their susceptibility to different influences depends on their group belonging. Agents are assigned their milieu at initialisation such that the milieu sizes from the SINUS study are mirrored. They stay within their milieu during the whole course of the simulation because the simulation only cares about openness towards queer people and changes in that openness alone are

[2]Those milieus are Conservatives (15%), Adaptive Pragmatics (24%), Precarious (5%), Hedonic Materialists (15%), Hedonic Experimentalists (12%), Social Ecologicals (8%) and Movers and Shakers (21%). For a detailed description see part 4.2.2.

not sufficient to justify shifting from one milieu to another as milieus consist of various social, economic and educational layers.

Besides her milieu belonging an agent‘s openness is her main property in the model. It is represented on a linear scale reaching from −1 (extremely closed) to +1 (fully open). This scale is somewhat artificial but it mirrors reality as psychology treats openness rather as a matter of degree than a black and white distinction.[3] The endpoints of the scale represent the most extreme but still (at least partially) seriously considered political views on LGBTQ issues. For Germany, this excludes criminalising LGBTQ people from the scale and rather sets pathologising them and excluding them from social and legal or health-care benefits as the extremely closed position. The initial value of openness is derived from the SINUS study (cf Section 4.2.2) and depends on the milieu: Conservatives‘ general sceptical opinion towards changes and “deviant” behaviour is mirrored by an initial openness of −0.73. Adaptive Pragmatics tend to get along with everyone and are thus relatively open (0.33) towards LGBTQ people. Precarious view them as a factor that makes their own struggle harder at the age of 14 (−0.6) and Hedonic Materialists dislike any lifestyle apart mainstream consuming (−0.33). Contrary to that, Hedonic Experimentalists partly identify with a queer lifestyle (0.67). Social Ecologicals feel more attracted to a traditional life themselves but also treasure toleration since early childhood (0.5). Movers and Shakers embrace any nonconformist lifestyle and view their own highly tolerant attitude (0.9) as superiority over their age-mates when they are 14.

While an agent belongs to her initial milieu throughout the whole course of the simulation, her openness can change in each period (which means monthly) and is influenced by the following three channels:

- **Impact of friends:** Each adolescent has a fixed number of friends with whom she exchanges her views regarding LGBTQ people. As friends trust each other, a child adopts her friends‘ views quite directly.

- **Impact of strangers:** Sometimes, children happen to talk about LGBTQ people with age-mates who are not their friends. Their opinion

[3] Cf for example Caligiuri et al. (2000) or Nevill & White (2011)

still has some impact but it is not trusted blindly and instead has to lie within a confidence interval to be taken seriously.

- **Impact of the adult world:** As explained above, adults impact children when talking to them about queer matters.

Before exploring these three channels in detail, it is important to keep in mind that communicating one‘s view regarding LGBTQ people is to be understood broadly. For example, a negative attitude towards them can be directly expressed by saying “Being gay is bad!” but more commonly it will surface implicitly for example in jokes about LGBTQ people or complaints about the coming out of a celebrity. Likewise, one can express their affinity to queer issues directly or indirectly and even non-verbally.

Impact of friends The number and kind of friends which an agent has stays constant throughout the simulation and is determined by her milieu. These numbers do not hold for every child of a milieu in reality but represent a stereotypical member as described by the SINUS study. Moreover, children in the model have five friends in average, which is backed by empirical findings (Wagner et al. 2008, cf data provided with the paper). Conservatives, Social-Ecologicals, Hedonic-Materialists and Precarious have five friends. Adaptive-Pragmatics who greatly value peer relations have seven friends and Hedonic-Experimentalists have eight since experiences with different people is a core element of their lifestyle. On the other hand, Movers and Shakers only have a single peer friend whom they deeply value. Generally, children tend to stick with members of their own milieu, as suggested by the SINUS study. Only Adaptive-Pragmatics have two of their five friends belonging to either the Precarious or the Hedonic-Materialist milieu (meaning in turn that members of those two groups have between two and three Adaptive-Pragmatic friends).

Adolescents highly value friendships and tend to fully trust their friends (Shell-Deutschland 2015, p 307); thus, they take their opinion about LGBTQ people seriously . In the model, all agents enter the process of updating their openness with its old value from any calculation because when discussing queer issues with friends, teenagers straightforwardly express their current believe. They calculate the mean of their own openness and the openness of the friend in question, separately for each friend. This is done simultaneously for all children and friendships. Then, the average of those means is calculated and set as the agent‘s new openness so that each agent updates her openness based on values before any update has taken place. This results in a fairly strong impact of friends consistent with tendencies towards social conformity in small groups explored by (Asch 1955, p 34). However, two agents who are linked as friends usually do not synchronise their openness values immediately (or within few periods) since their cliques do overlap but are not identical; the only exception from that being Movers and Shakers who only have a single friend with whom they intensely discuss and agree on most matters.

Impact of strangers Adolescents spend most of their free time with friends but they occasionally also meet other age-mates and exchange views on queer issues with them. This may happen in various situations, e.g. on the bus, in sports clubs, at parties or even in the school yard - as longs as the setting is not immediately influenced or supervised by an adult. The model represents these random discussions by agents moving to a random spot in the model world each period and exchanging the openness with those others who are at the same spot.[4] Given size and population density of the model world, children have such exchanges with one or more age-mates in average every other month.

While children trust their friends‘ opinions “blindly”, they are more wary about what strangers state (Freitag & Traunmüller 2009). To represent this behaviour in the model, for each spot in the world with more than one agent on it, the average openness of all agents on the spot is calculated. However, agents only adopt this average if it is significantly close to their own openness, i.e. at most 0.5 more open or less open than it. Members of different milieus are differently receptive to strangers they meet and thus the general factor of 0.5 is modified with a milieu specific factor to represent milieu specific confirmation biases (Kahneman 2011, p. 107). Only Precarious who struggle to find their own position and thus look to others have a confidence of $1 * 0.5 = 0.5$. The confidence level of Adaptive-Pragmatics and Hedonic-Experimentalists

[4]Note that on this views all communication is reciprocal, i.e. one adolescent does for example not overhear someone else talking about LGBTQ people without engaging actively in the conversation.

is $0.7 * 0.5 = 0.35$ since members of these groups are still quite open towards strangers. Social-Ecologicals and Hedonic-Materialists entertain different lifestyles but they are equally committed to theirs and are considerably wary about strangers, as represented by a confidence level of $0.3 * 0.5 = 0.15$. Conservatives mainly focus on their equally conservative friend and Movers and Shakers generally try to stay away from most age mates. Therefore both groups only take those strangers seriously who almost share their own opinion (confidence level $0.1 * 0.5 = 0.05$). This updating can be understood as a variant of the Deffuant-Weisbuch-Dynamics (Deffuant et al. 2000) where the calculated average takes the role of the opinion value of the second agent in updating the opinion of the first. However, the more explicit definition of confidence as an interval introduced by Hegselmann and Krause is used and 0.5 is picked as its size, following them, too: They identify 0.25 on the unit interval, which is equivalent to 0.5 in this model, as a paradigmatic case of reaching consensus reliably (Hegselmann et al. 2002, p. 15). This guarantees an impact of strangers in the model which resembles how adolescents treat them in reality: Their views are taken seriously and probably adopted to a point where everyone agrees with each other but they do not posses the credit of trust that friends have.

Thus, there are two main differences between impact of friends and impact of strangers: Firstly, every friend matters each month while a stranger‘s view is not regularly taken into account (usually, two agents will meet at the same patch at most once or twice during the 48 simulation periods). Secondly, the openness of friends is always fully considered whereas strangers are only taken serious if their stance is sufficiently close to the one of the agent in question.[5]

Impact of the adult world Her peers play an important role in the development of an adolescent‘s values but this development is also impacted by adults in different ways. The model captures these impacts (with regard

[5] Note here, that the model allows for friends meeting in the same spot, too. In this case, a friend is treated as any other agent on the spot when calculating the impact of strangers but additionally fulfils her role as a friend.

to LGBTQ people) in a term that is added to each agent‘s openness every period:[6]

Function 1 (Adult impacts).
$(\theta * ReligiousEducation + \iota \cdot OtherSubjects + \kappa * RETeachers + \lambda * OtherTeachers + \mu * Church + \nu * Family)/12$

The size of a weight varies between milieus but each weight is always positive and the sum of all weights is strictly smaller than 1 for each milieu. The weights for the different milieus and a rationale for their distribution based on the SINUS study are described in the next section. Weights were chosen to represent the strength of the yearly impact of a factor but as the term is used each period (meaning each month in real time), it is divided by 12. In reality, precise strengths of influences presented below vary depending on where a child in question lives, which school she attends and socio-economic factors. However, the weights used in the model are a plausible idealisation and moreover model dynamics are resilient towards changes in these weights.

While weights depend on a child‘s milieu, parameter values themselves are externally given and the same for all agents. Each parameter can take values between -1 and 1. $Church$, $Theology-Uni$ and $EducationAgendastate$ are primitive, all other values are derived from external parameters.

$Family$ directly mirrors $Society$ because a child‘s family lives within society and will thus in average hold its values.

$RETeachers$ derive a fourth of their openness from the openness of society as a whole but since they are connected with the church, its explicit openness is equally important to them. The remaining half of their openness value is derived from their $TheologicalTraining$ at university. The latter has a notable impact because at university, training of theological knowledge and personal development go hand in hand. It is important to bare in mind that not only teachers in schools but all religious guides who enjoyed training at university are included.

As described for the adolescents‘ families above, $OtherTeachers$ derive their openness directly from society. Again, the group of these teachers in the

[6]If an agent‘s openness after adding the term is below -1 or above 1, it is automatically capped.

model not only consists of teachers in schools but of all sorts of guides who are accepted as role models by teenagers. Therefore, the weight of this factor can be high for a milieu, even if children of that milieu do not pay much respect to teachers but spend their free time with social workers or in sport clubs.

Education agenda of the church is the average of the openness of the institutional church and of scientific theology done at universities. A lack of interdependence between it and *Church* is plausible because on the one hand, theology at universities is free from ideological predispositions and often tries to emancipate from doctrines of the church. On the other hand, the institutional church sometimes consults theologians from universities but is free to waive their advises afterwards and often does so.[7] Thus, scientific theology is left to efficiently influence the church position only in specific cases as setting up an education agenda (where expertise in pedagogical matters is important).

Figure 4.1 shows the causes determining, how open religious education in school is. Church and state have an equal say in setting the curriculum because both parties must approve it (Religionswissenschaftlicher Medien- und Informationsdienst – REMID 2012). The curriculum, on which church and state agree, shapes the openness of actual religious education lessons to 75%, while the remaining 25% are under each teacher‘s influence because she can treat parts that she disagrees with less carefully or shorter.

The causes determining *OtherSubjects* are shown in figure 4.2. The curriculum is set by the state alone and as for religious education, it determines to 75% how lessons actually look like. The teaching stuff of all profane subjects partially consists of theologically trained teachers because in Germany teachers usually study two subjects.[8]

All factors together determine the direction and strength of adults‘ influences on adolescents‘ openness towards LGBTQ people. The specific Together with impacts from friends and other age-mates, they constitute the model dynamics.

[7]For example, Dabrock et al. (2015) were asked to compose a new guideline on sexuality for the Protestant church in Germany but the resulting text was too progressive and thus not officially published by the church.

[8]Pastors sent to schools as teachers and guides of Christian free time activities are exceptions to that; this is taken into account when determining the share of religious education teachers.

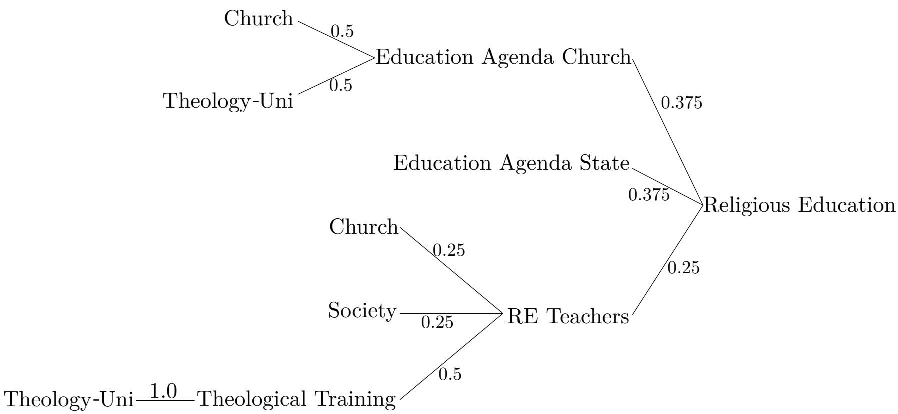

Figure 4.1: Causes determining the openness of religious education.

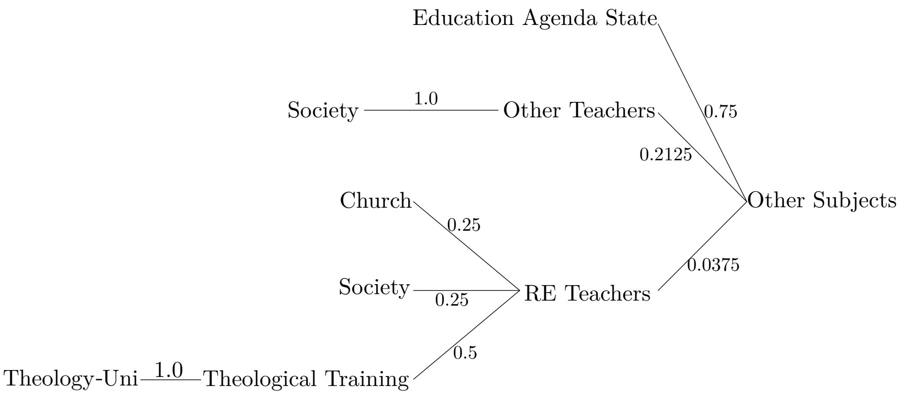

Figure 4.2: Causes determining the openness of all subjects but religious education.

4.2.2 Grouping children using the Sinus Study

"SINUS is an independent, owner-managed institute for psychological and social science research and consulting" (SINUS 2016). Its data is used by companies (mainly for marketing purposes) and the church.[9] In Germany, the SINUS institute carries out a specific milieu study for children aged 14 to 17. Its methodology has quantitative as well as qualitative components: 2000 children were given a questionnaire to distinguish different milieus and broadly describe their core characteristics. This allowed to match 71 adolescents who were selected as interview partners and their specific descriptions with the overall milieus (Calmbach et al. 2016, p. 33). The groups in the model presented below in this section are directly derived from the seven milieus, which SINUS defines. The descriptions summarise the relevant parts of the overall picture of each milieu drawn in the SINUS Youth Study 2016 resulting in specific weights of external influences:

Conservatives - 15% Family-oriented local rooted adolescents with a strong sense of responsibility. They feel uncomfortable with change, deliberately pursue traditional values and look for institutions which give them security, as the church does. Therefore, they spend their free time in church communities or ecclesiastical youth organisations and live a traditional piety there. Their opinion is that believing implies belonging to an institutional church which in turn implies practising; faith has a distinct normative dimension for them. They socialise with their like and avoid deviants in order not to get in conflict with authorities.

Function 2. $(0.15 * ReligiousEducation + 0.1 * OtherSubjects + 0.15 * RETeachers + 0.1 * OtherTeachers + 0.05 * Church + 0.2 * Family)/12$

Conservatives' general sceptical opinion towards changes is mirrored by their initial share of open and closed group members: Only 2 of the 15 are open at start of the simulation (meaning at their 14th birthday).

[9] Consider e.g. internal documents from the diocese of Speyer working with results from the SINUS study for adults (Diocese-Speyer 2015). Furthermore the Federation of German Catholic Youth (BDKJ) and the taskforce for pastoral ministry youth of the Catholic episcopal conference in Germany are partners of the SINUS youth study 2016 (Calmbach et al. 2016, pp. 480-483).

Adaptive Pragmatics - 24% Meritocratic mainstream with a markedly pragmatic outlook on life. They are prepared to flexibly adapt to changes while looking for fun and entertainment as well as strong social ties, especially within their families. Faith plays no role in their highly organised daily life. They do not seek knowledge for its own sake but can work hard for school if they feel that it supports preference fulfilment (at least in the medium run). Adaptive Pragmatics are aware that they can gain by learning from adults' practical advise and as a by product of this also pay attention to value education in family, school and organised (profane) free time activities.

Function 3. $(0.05 * ReligiousEducation + 0.25 * OtherSubjects + 0 * RETeachers + 0.05 * OtherTeachers + 0 * Church + 0.4 * Family)/12$

Precarious - 5% Precarious children struggle to emancipate from their families to escape their miserable lives. They see no justice in society, and tend to believe populists; they are uncomfortable with changes due to their sense of exclusion and embitterment. Because they come from difficult families, they spend much of their free time at activity centres under guidance of social workers or sail close to the wind with their friends, which often involves violence. They fear the future but at the same time hold unrealistic hopes for it; however, those are not religious in nature since they usually have no connection with religion.

Function 4. $(0 * ReligiousEducation + 0.05 * OtherSubjects + 0.05 * RETeachers + 0.2 * OtherTeachers + 0 * Church + 0.1 * Family)/12$

Hedonic Materialists - 15% Lower class highly valuing representation by consuming trendy brands. Thus, these adolescents care much about free time, party, shopping and money to afford those things. Family is important to them and they treasure a traditional, harmonic form of it and want to have such a family themselves later. But for now they spend much time with their many friends partying and reject any authorities which limit their lifestyle or get them to work for school. They are mainstream-oriented in any respect including gender stereotypes and neither show affinity to sub-cultures nor to the church.

Function 5. $(0 * ReligiousEducation + 0.05 * OtherSubjects + 0.025 * RETeachers + 0.125 * OtherTeachers + 0 * Church + 0.55 * Family)/12$

Hedonic Experimentalists - 12% Nonconformists who treasure freedom, individuality, risk and fun for the sake of their self-realisation. Due to their border crossing, wayward lifestyle they often have conflicts with their parents, teachers or fellow adolescents. Because they celebrate any sort of movement and change in their lives, they do not care about school, family or any other "traditional" institution. Instead, they want to emancipate from the mainstream and develop their own style by experimenting around with e.g. their sexuality. In that field, they are open to everything and openly discuss everything with their peers. Hedonic Experimentalists feel devoted to having fun here and now, not making plans for the future. Naturally, they do not care about church or its values at all.

Function 6. $(0 * ReligiousEducation + 0.05 * OtherSubjects + 0 * RETeachers + 0.1 * OtherTeachers + 0 * Church + 0 * Family)/12$

Social Ecologicals - 8% Socially engaged and socio-critical and open to alternative ways of life as long as they fit their normative concepts which are generally liberal and involve a strong sense of equality. They organise their free-time themselves and like reading or are keen on learning and on getting to the root of a topic. That applies to religion as well: Faith plays an important role for many Social Ecological adolescents and they are open to doctrines of the church but do not follow them blindly. Instead, they find their own faith in accordance with their other values. Nevertheless, their opinion is that believing implies belonging to an institutional church which in turn implies practising. For that purpose, they often go to youth-religious places (e.g. Taizè).

Function 7. $(0.15 * ReligiousEducation + 0.2 * OtherSubjects + 0.1 * RETeachers + 0.15 * OtherTeachers + 0.05 * Church + 0.175 * Family)/12$

Movers and Shakers - 21% Nonconformist ambitious avant-garde seeking new frontiers and new solutions. They hold diverse values balancing self-realisation and meritocracy. This is mirrored in their flexibility and their affinity to competition where they feel superior to age-mates. They constantly try to expand their horizon and thus strongly dislike conservative religious morals, control and authority but at the same time enjoy contact with older children or adults. They highly treasure diversity in fashion, culture and ways of life and compose their own style from this diversity. They are often single themselves and instead develop a close and exclusive but platonic relationship with a friend, because they fear a relationship would limit their freedom too much.

Function 8. $(0.05 * ReligiousEducation + 0.35 * OtherSubjects + 0 * RETeachers + 0.2 * OtherTeachers + 0 * Church + 0.05 * Family)/12$

4.3 Simulation Results

Simulation results are presented in two steps: The first one aims on understanding fundamental properties of the model, by looking at the behaviour of adolescents without external influences (part 4.3.1) and by varying those influences one at a time (part 4.3.1). In its second step, the analysis turns towards potential states of German society.

4.3.1 Model mechanics

Development without external influences

Figure 4.3 depicts the average result of the 50 simulation runs for all external variables set 0, comparing the average overall openness with the average openness of each milieu.

This involves two steps of aggregation demanding to be justified. The first one is to look at how agents in a single run (and a single milieu) behave in average. Doing that is reasonable firstly because the average of each group is of the greatest political interest and secondly because behaviour of the mean can provide informative clues on where one must seek for more detailed explanations and investigate single agents and thus dispersion measures are also analysed. The second aggregation is the one of multiple runs instead of looking at single runs which does not risk overlooking any details here because the dispersion of values is sufficiently small.[10] The only feature not grasped by an aggregation over runs are oscillations of the mean openness of some milieus on the same level between time steps which are explained below; but this does not impact the aggregation faithfully representing general trends.

The figure shows a small increase of overall openness over time and a clear distinction between milieus: The openness of Conservatives and Movers and Shakers remains constant during the 48 simulation periods of all runs because they do not have friends outside their respective milieu and are very wary in encounters with other age-mates.

Contrary to that, Adaptive Pragmatic, Hedonic Experimentalist and Precarious children change their openness over time; Adaptive Pragmatics have both Precarious and Hedonic Experimentalist friends meaning that those three milieus are closely linked together. Namely, Adaptive Pragmatics and Hedonic Experimentalists become similarly open. Parallel to that, Adaptive Pragmatics pull their Precarious friends towards their own position regarding LGBTQ people. Moreover, the large confidence interval of Precarious adolescents causes them to trust most strangers they encounter and adapt their openness accordingly. And since most other agents are significantly more open than her, a random encounter usually makes a Precarious agent more open. Both factors together explain why Precarious change their openness quickly.

The two milieus not discussed so far - Social Ecologicals and Hedonic Materialists - are similar in their friendship structure, as they have only friends from their own group, and their attitude towards strangers, as they are both quite wary with a group specific confidence modifier of 0.3. Nevertheless, Social Ecological and Hedonic Materialist agents behave differently in simulation because of their different initial openness values: Social Ecological children frequently take seriously opinion exchanges regarding queer issues with age mates they encounter randomly. Thus, they continuously adapt their own openness to the average one of the milieus close to them, which explains why they become slightly less open during the first simulated year but why then

[10] Standard deviation for the overall openness is 0.6% of the parameter space and for the Social Ecological milieu (the one with the largest standard deviation) it is 1.8% of the parameter space. Range of openness is 3.0% of the parameter space overall and 9.4% for the Precarious milieu (the one with the largest range due to oscillations of the mean for single runs).

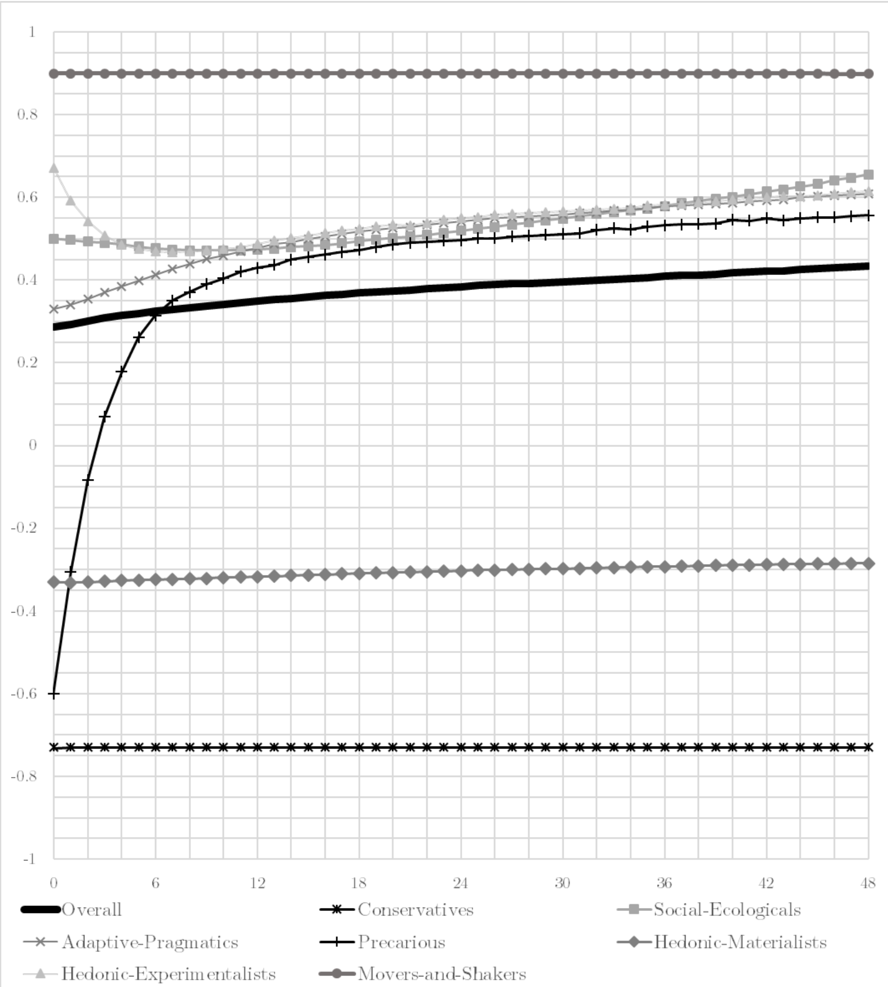

Figure 4.3: Development of openness over time, for $Church = 0$, $Theology-Uni = 0$, $EducationAgendaState = 0$, $Society = 0$

this trend reverses and Social Ecologicals end up more open after four simulated years than they were initially. Hedonic Materialists in contrary quickly stop seriously discussing queer issues with age-mates who are not their friends because no members of other milieus have a mindset similar to theirs.

Overall, agents' interactions based on only two of their three mechanisms to update their openness already leads to complex outcome patterns and namely provides following insights into model mechanisms

- If left to themselves, most children would become more open-minded towards LGBTQ people than they currently are at the age of 14 in Germany (represented by the initial situation in the model).
- Randomness:
  - It enters the model dynamics mainly via children's encounters with strangers and only to a smaller extent in friendship formation.
  - It plays only a minor role since differences between simulation runs are considerably small.
- An agent's openness does not necessarily develop monotonically but it sometimes oscillates slightly on one level (e.g. for the Precarious milieu) or the agent becomes more close in the beginning and grows more open again afterwards (e.g. Social Ecologicals or Hedonic Materialists).
- The dynamics do not stabilise within the practically relevant time frame.[11]

Variation of single parameters

Figure 4.4 compares the changes in overall openness given extreme values of the four external variables. While those extremes are highly unrealistic in reality (at least in Germany), they are able to provide boundaries for the possible impact of a factor: Institutional church which is said to prohibit openness towards lifestyles violating its conservative moral norms actually only can raise closeness only marginally while there is a potential for raising overall openness, if the church itself proclaims it distinctly. Furthermore,

[11] The median time to arrive at an equilibrium state in the sample of 50 simulation runs was 1298 steps, with a minimum of 907 time steps, and five runs not reaching an equilibrium within 100000 time steps.

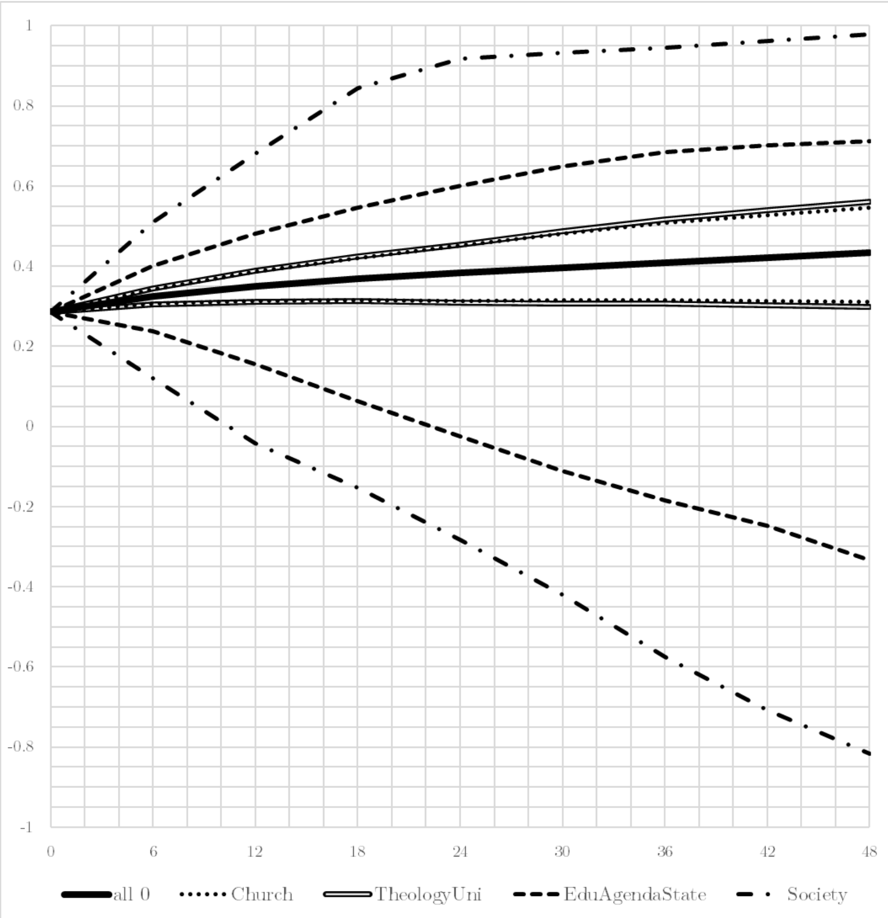

Figure 4.4: Comparison of average overall openness over time given modifications of single parameters between 1 (upper lines) and −1 (lower lines), keeping all others constant at 0.

many Christian-fundamentalists rejecting sexual plurality accuse the state of "depraving the youth" by a too open education. The model suggests that these accusations are also pointless, since the education agenda of the state has a far higher potential for leading to closeness of adolescents than to their openness.

Impact of the two clerical variables on the system is fairly limited. The church has actually accepted its nowadays diminished impact on many members of society, as internal documents suggest (Diocese-Speyer 2015). Civil society seems to play a very important role for the openness of the adolescents maybe because of a new wish among them to adapt to conventions (Calmbach et al. 2016, p. 475).

4.3.2 Model Setups Resembling Potential States of Society

Open-minded real world scenario $Church = -0.2$; $TheologyUni = 0.3$; $EducationAgendaState = 0$; $Society = 0.1$[12]

Education sends no clear message in favour or disfavour of sexual plurality, society is slightly open, especially academic circles (including the theological ones). The institutional church sticks to a more closed view but is - as Figure 4.5 shows - outweighed by other actors in society both overall (adolescents are 0.59 open after four years, compared to only 0.43 without external impacts) and for each milieu; all adolescents including Conservatives, who put great trust in what the church says, have a clear trajectory towards acceptance of sexual plurality during the whole simulation time. However, the process of becoming more open happens relatively slowly and thus changes within four years are only moderate: Altering attitudes of many individuals does take a long time in a pluralistic society. Movers and Shakes stick out because they become fully open-minded in 38 month but their initial opinion about queer issues is close to that full openness already.

[12] An open-minded as well as a close-minded scenario is presented, since there are different perspectives, how open the relevant external influences in Germany currently are. Uncertainty is two-fold here: First, it is not clear, which signals the adolescents receive, e.g. to which statements from the institutional church they listen. Second, even if the set of relevant signals could be exactly defined, one would need very precise criteria for evaluating every single such signal.

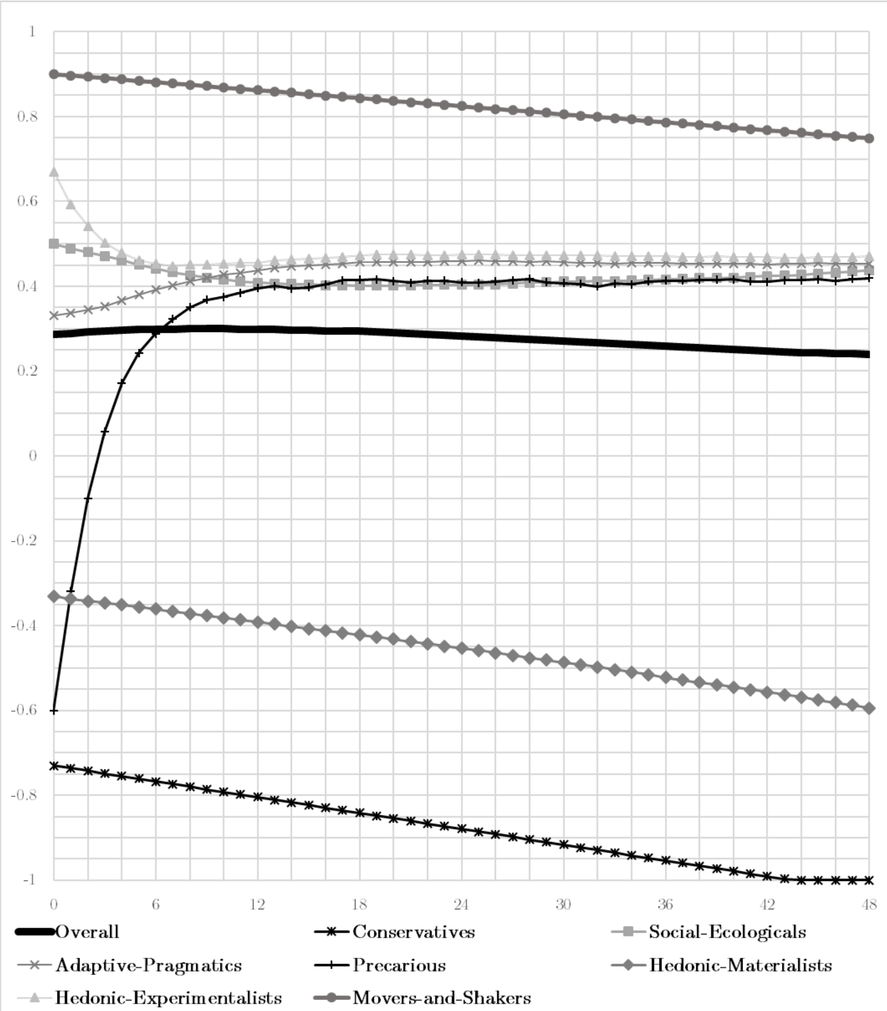

Figure 4.5: Open-minded real world scenario: $Church = -0.2$; $TheologyUni = 0.3$; $EducationAgendaState = 0$; $Society = 0.1$

Close-minded real world scenario $Church = -0.3$; $TheologyUni = 0$; $EducationAgendaState = 0$; $Society = -0.1$

Figure 4.6 depicts this situation, where society is slightly close-minded and institutional church holds a distinctly traditional moralistic opinion. In average, overall openness decreases over time: Conservatives who are greatly influenced by the regressive institutional church become fully closed in less than four years and they also impact Hedonic Materialists. Social Ecologicals, Adaptive Pragmatics, Hednonic Experimentalists and Precarious end up slightly less open than in a situation without influences from adults but they still maintain their general open-minded attitude towards LGBTQ people. The strong bonds between agents of the four milieus make them resilient towards external impacts in the relevant time frame. Movers and Shakers are more open than these four milieus but on a clear trajectory towards closeness, since they are interested in all channels of education including religious education and also talk much to older members of society who have a slightly critical attitude of LGBTQ people in this scenario.

Christian-Conservative perception of the "Bildungsplan 2015" in Baden-Wuerttemberg $Church = -0.5$; $TheologyUni = -0.3$; $EducationAgendaState = 1$; $Society = -0.4$

This scenario reflects the view of those opposing the education agenda which the he green-red government of Baden-Wuerttemberg had planned to become effective in 2015. These groups assume it to be a broad consensus in society that LGBTQ people are "sexual deviations"[13] and that intersexuality is like "genetic defects".[14] The education agenda in contrary is seen as maximally open, since it does not only promote acceptance of sexual plurality against the majority opinion in society but even indoctrinates children to become lesbian, gay, bi-, trans- or intersexual (according to its opponents).

Figure 4.7 shows that strong and opposed external influences do largely contribute to polarised individual opinions. Furthermore, the extreme education agenda value indeed causes Social Ecologicals, Adaptive Pragmatics,

[13]"sexuelle Abweichungen" (Zukunft-Verantwortung-Lernen 2016)

[14]"Gen-Defekten" (Zukunft-Verantwortung-Lernen 2016). Disclaimer: This expresses no disrespect for people with genetic defects of the author but simply presents the position of the source.

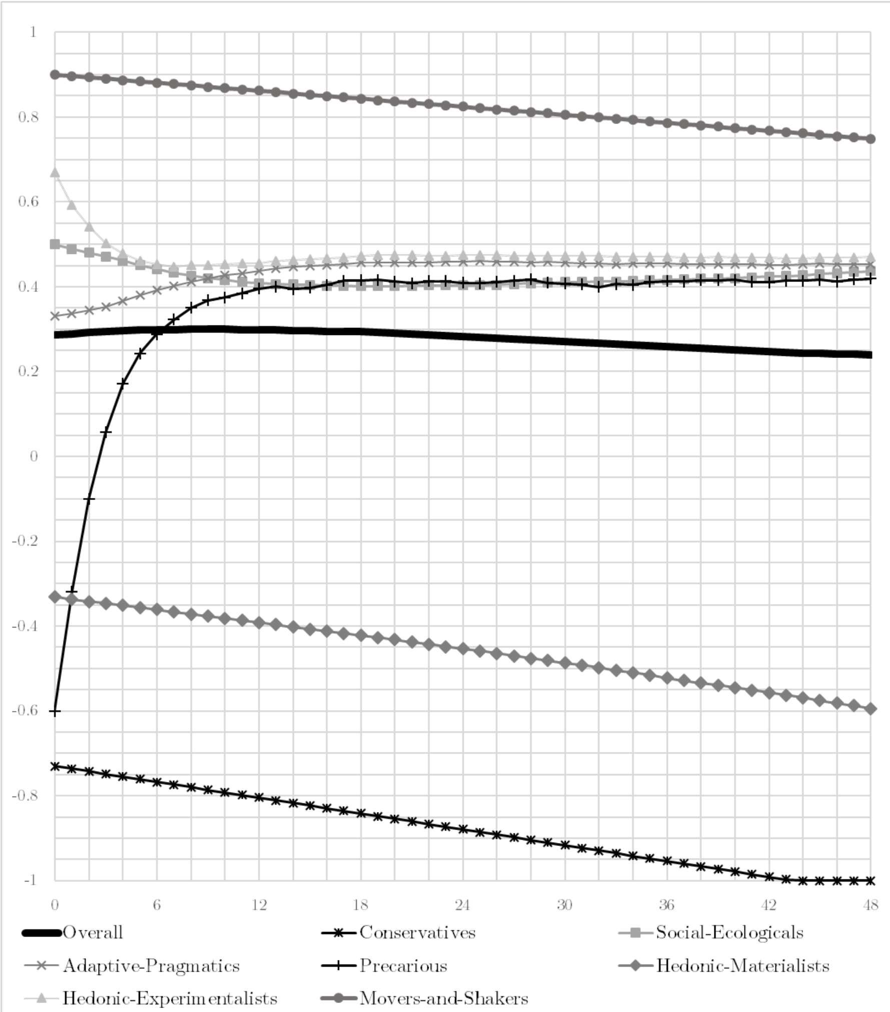

Figure 4.6: Close-minded real world scenario: $Church = -0.3$; $TheologyUni = 0$; $EducationAgendaState = 0$; $Society = -0.1$

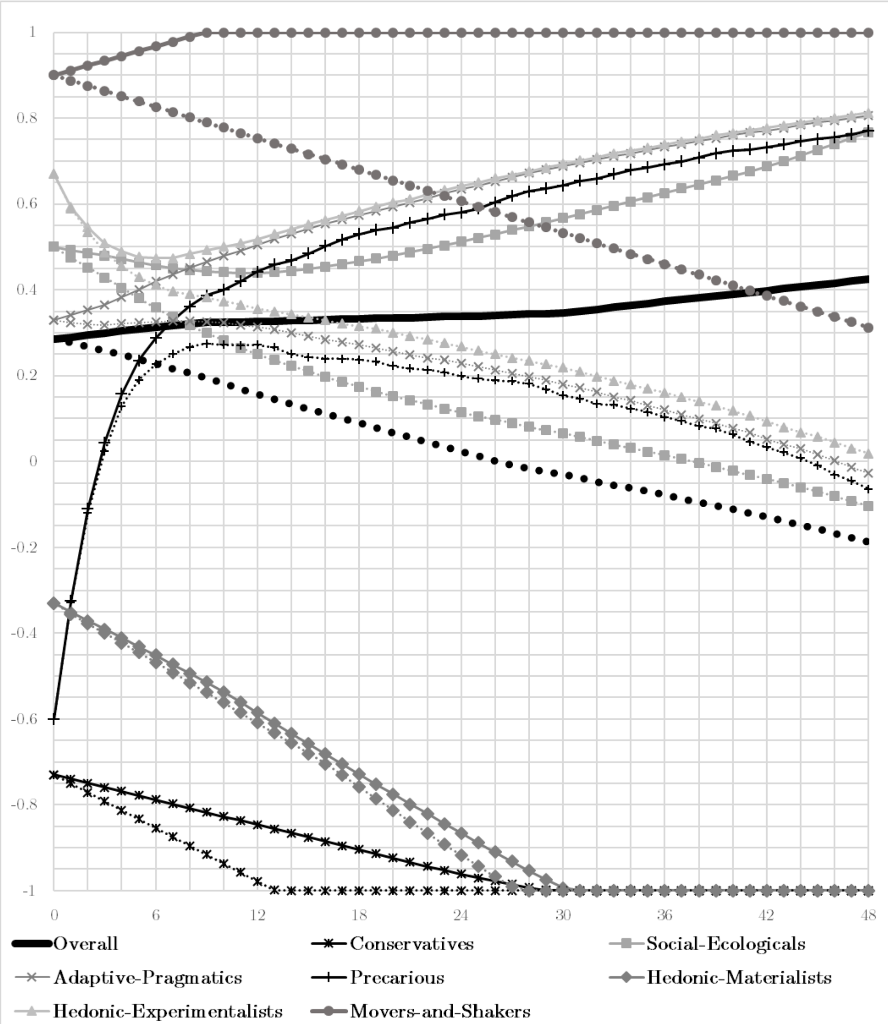

Figure 4.7: "Bildungsplan 2015": $Church = -0.5$; $TheologyUni = -0.3$; $EducationAgendaState = 1$ (0 for dotted lines); $Society = -0.4$

Precarious, Hedonic Experimentalists, and Movers and Shakers to become open, whereas they would end up closed if the state would not aim on teaching any values regarding openness. However, the education agenda does actually bring about a final situation after four years that resembles the one without any external influences both in terms of average openness and of how milieus feel about LGBTI people. As the opponents of the education agenda express their discomfort with such a state, they reveal that they have no problem with indoctrination of children in general - as long as their values are indoctrinated.[15]

4.4 Why impact of church and formal education on adolescents‘ value development is severely limited - but the one of civil society is not

Three main facts, which likely also hold for younger children and adults, are revealed by the simulation study on adolescents‘ value development:

- Society can distinctly shape the model outcome in some settings even when changes are only moderate.
- The influence of academic theology, institutional church and government education agenda is limited and contradicts the common perception of these institutions.
  - Institutional church and academic theology have higher potential to induce openness than closeness.
  - The government education agenda has higher potential to induce closeness than openness.
- All agents except Precarious ones tend to stick to their initial openness level for small to medium changes in external factors.

[15] This is indirectly admitted by the opponents of the education agenda by demanding sovereignty of the parents (Zukunft-Verantwortung-Lernen 2016).

The first statement reflects neo-conventionalism and a view of one‘s parents as trustworthy role models which the SINUS study (Calmbach et al. 2016, p. 475) found among adolescents: Openness of family is directly derived from the external value of society. While there are vivid dynamical interactions within and between milieus, openness of society as external variable can decide in which direction those dynamics work, because of its initial push before path dependencies kick in.

Although the other three variables also affect simulations from their start, their impact is limited. Commonly, clerical influences are expected to be traditionalistic and advocating a less open treatment of sexual plurality, while education policy seems to be a government tool to promote openness towards LGBTI people. However, the model shows that neither of the factors can work that way in the model: Closeness of academic theology or institutional church makes fewer adolescents turn closed than openness makes turn open: The milieus caring most about what church and theology (in form of religious education) say tend to become closed anyway. Thus, a church sending messages supporting this tendency to closeness has little impact while messages promoting openness can reverse the thinking of church-affine milieus. Likewise, a closed education agenda attracts more children to closeness than an open one attracts to openness since milieus affine to education have a predisposition to become open-minded.

That agents tend to stick to their initial views aids in validation of the model as realistic and so does the exception of Precarious children joining the position of their Adaptive Pracmatic friends: The initial setting of the model tries to represent children when they turn 14. At this age, friends play a major role in value development whereas in earlier childhood, different (and in case of the Precarious sometimes LGBTQ phobic) factors impact a child‘s values.

4.5 Concluding Remarks

The simulation study offers mechanism based explanations for how adolescents in Germany develop their stance towards sexual plurality given their environment of family, school, church, leisure activities and peer interactions.

However, when trying to predict specific outcomes in terms of how open adolescents of different milieus become precisely for some given circumstances, one should be careful: There are important regional differences in Germany concerning religion and religious education and the SINUS milieus are likely unevenly distributed over Germany, too. This may lead to regionally different mechanisms whose aggregation differs from the dynamics observed for aggregated data. Therefore, using the model with the SINUS study as input data to make statements about a specific town would be a *fallacy of misplaced concreteness* (Whitehead 1925, ‘48, pp. 53). Furthermore, openness of adolescents‘ families is unanimously represented for all milieus by openness of society, whereas there likely is an empirical relation between milieu belonging of children and parents. Lifting this assumption of all families being equally open and instead making their openness milieu dependent poses a possibly fruitful way of expanding the model and bringing it closer to reality.

The model monitors openness of a single age group during its youth within a given shape of society, church and education. However, extending the model to a longer time frame could reveal generational effects: Adolescents grow up to be parents, teachers or guides themselves, meaning that their value development impacts the value development of their children, pupils and mentees, too. Such a long term-view had to internalise the four external variables of this study, foremost openness of civil society which is revealed as the most influential factor in the model:

If civil society has a dedicated position regarding queer people, the resulting dynamics among adolescents are resilient towards external pressure by government education, academic theology or institutional church; simply changing a short-term influence on children‘s development process is not (necessarily) fit to alter that process as the ones changing the influence want. Complex interactions between actors in the modelled system lead to unpredictable emergent results. Put differently, young citizens perceive and weight different influences differently and form their own opinion; thereby, they guarantee the persistence of a strong civil society as long as they grow up in one.

References

Ahmad, S. & Bhugra, D. (2010). Homophobia: an upyeard review of the literature. *Sexual and Relationship Therapy*, *25*(4), 447–455

Asch, S. E. (1955). *Opinions and social pressure.* San Francisco, Calif: Freeman

Bhugra, D. (1987). Homophobia: A review of the literature. *Sexual and Marital Therapy*, *2*(2), 169–177

Caligiuri, P. M., Jacobs, R. R. & Farr, J. L. (2000). The attitudinal and behavioral openness scale: Scale development and construct validation. *International Journal of Intercultural Relations*, *24*(1), 27–46

Calmbach, M., Borgstedt, S., Borchard, I. & Flaig, P. M. T. B. B. (2016). *SINUS: Wie ticken Jugendliche 2016?*

Dabrock, P., Augstein, R., Helfferich, C. & et al (2015). *Unverschämt - schön. Sexualethik: evangelisch und lebensnah*

Deffuant, G., Neau, D., Amblard, F. & Weisbuch, G. (2000). Mixing beliefs among interacting agents. *Advances in Complex Systems*, *3*(01n04), 87–98

Diocese-Speyer (2015). Sinus Pfarreianalyse

Freitag, M. & Traunmüller, R. (2009). Spheres of trust: An empirical analysis of the foundations of particularised and generalised trust. *European Journal of Political Research*, *48*(6), 782–803

Hegselmann, R., Krause, U. et al. (2002). Opinion dynamics and bounded confidence models, analysis, and simulation. *Journal of artificial societies and social simulation*, *5*(3)

Kahneman, D. (2011). *Thinking, fast and slow.* New York: Farrar, Straus and Giroux, 1. ed. edn.

Kultusministerium (2016). Bildungsplan Badenwürttemberg
URL www.bildungsplaene-bw.de/,Lde/LS/BP2016BW/ALLG/LP

Nevill, R. E. & White, S. W. (2011). College students' openness toward autism spectrum disorders: Improving peer acceptance. *Journal of Autism and Developmental Disorders*, *41*(12), 1619–1628

Queer.de (2015). Heftig umstrittener Entwurf
URL www.queer.de/detail.php?article_id=24603P

Religionswissenschaftlicher Medien- und Informationsdienst – REMID (2012). Religionsunterricht in Deutschland
URL www.remid.de/info_religionsunterricht/

Shell-Deutschland (Ed.) (2015). *Jugend 2015: 17. Shell Jugendstudie*. S. Fischer Verlag

SINUS (2016). SINUS-Institut Website
URL www.sinus-institut.de/

Tagesspiegel (2014). Wieso ist der Lehrplan so umstritten?
URL www.tagesspiegel.de/politik/sexuelle-vielfalt-im-unterricht-wieso-ist-der-lehrplan-so-umstritten/9326766.html

Wagner, G. G., Göbel, J., Krause, P., Pischner, R. & Sieber, I. (2008). Das Sozio-oekonomische Panel (SOEP): Multidisziplinäres Haushaltspanel und Kohortenstudie für Deutschland–Eine Einführung (für neue yearnnutzer) mit einem Ausblick (für erfahrene Anwender). *AStA Wirtschafts- und Sozialstatistisches Archiv*, *2*(4), 301–328

Whitehead, A. N. (1925, '48). *Science and the modern world*. PELICAN MENTOR BOOKS

Zukunft-Verantwortung-Lernen (2016). Petition zum Bildungsplan 2015
URL www.bildungsplan2015.de