A GENERATIVE MODEL OF

TRUST FORMATION AND GENERATIONS

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ABSTRACT

A Generative Model of Trust Formation and Generations

This thesis introduces an agent based simulation of a multi-generation population with a dynamic trust network in a world with limited resources. This population is assumed to be under evolutionary pressure incurring costs of life and individuals must act wisely in order to survive and reproduce. Over their lifetimes individuals encounter strangers, assess their reliability and build lasting connections. They retain the memory of all past interactions and re-evaluate their trust in others and in themselves after all actions. Individuals employ various strategies to decide their course of action and take advice from their trust networks. We use this generative model to investigate the emergence and consequences of generational differences under various conditions of the world.

ÖZET

Güven Oluşumu ve Kuşakların Üretken Modeli

Bu çalışma sınırlı kaynaklara sahip bir dünyada dinamik bir güven ağına sahip çok nesilli bir popülasyonun etmen tabanlı bir simülasyonunu sunmaktadır. Bu nüfusun yaşamsal ihtiyaçları dolayısıyla evrimsel baskı altında olduğu ve bireylerin hayatta kalıp üreyebilmek için doğru eylemlerde bulunmaları gerektiği varsayılmaktadır. Yaşamları boyunca bireyler yabancılarla karşılaşır, güvenilirliklerini değerlendirir ve kalıcı bağlantılar kurarlar. Bireyler geçmişteki tüm etkileşimlerinin hafızasına sahiptir ve tüm eylemlerinden sonra kendilerine ve başkalarına olan güvenlerini güncellerler. Buna bağlı olarak, eylemlerine karar vermek için çeşitli stratejiler kullanır ve güven ağlarının tavsiyelerini değerlendirirler. Bu üretken modeli, dünyanın çeşitli koşullarında nesiller arası farklılıkların ortaya çıkışını ve sonuçlarını araştırmak için kullanıyoruz.

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LIST OF TERMS AND ABBREVIATIONS

Acquaintances	The set of others that the individual knows
Action domain	The set of action alternatives and their interdependency
Action frequency	Relative prevalence of an action among its alternatives
Action terms	Number of decisions taken by individuals annually
Actualized benefit	Benefit gained by the individual after an action
Ancestors	Initially created population
Autonomy	Self reliance of an individual while deciding
Benefit	Unit of an Individual's gain for an action
Communication noise	Occurrence of an error in communication
Competence	Ability to select the better action among alternatives
Competition domain	Action domain with negative frequency dependency
Confidence vector	Relative strength of tendencies for decision strategies
Cooperation domain	Action domain with positive frequency dependency
Council	Most trusted subset of an individual's acquaintances
Council size	Maximum number of council members
Encounter	The act of meeting another individual during a decision
Exploratory tendency	Stochastic exploration tendency of individuals
External impact	A change in simulation parameters during run-time
Feedback probability	Probability that the advisee is notified of resolution
Frequency dependency	Dependence of benefits on action frequencies
Following	Reliance of an individual on arbitrary encounters

Living cost	Annual benefit expenditure of the individual
Neutral domain	An action domain with no frequency dependency
NFD	Negative frequency dependency
Nominal benefit	Intrinsic value of an action in the world
Oracle	Theoretical individual with maximum reliability
PFD	Positive frequency dependency
Reliability	Quantitative accuracy of an estimate or world model
Salience weight	Exponent of decay for action frequencies
Sample size	Number of observations of an action by an individual
M_3	Skew of the trustedness distribution
Social norm	Action with the best actualized benefit in PFD
Socialness	Reliance of an individual on its council while deciding
Stranger	A previously unknown individual who is encountered
Strategy block	A group of like aged individuals under same tendency
Strategy signature	Strategy state in an equilibrium
Strategy state	Agewise prevalence of decision strategies in a society
S_3	Three dimensional simplex
Wealth	Material wealth and well-being of individuals
World model	An individual's representation of the world

LIST OF SYMBOLS

a	Action a
$\mathbb{A}_i(t)$	Set of others that individual i knows at time t
α_ϕ	Salience weight of action frequencies
$B(a,t)$	Nominal benefit return of action a at time t
$B^*(a,t)$	Actualized benefit return of an action a at time t
$\underline{\hat{b}_i}(t)$	Aggregate benefit expectations by individual i at time t
$\underline{b_i}(t)$	Vector of estimated benefits by individual i at time t
$b_i(a,t)$	Estimated benefit by individual i of action a at time t
$\beta(t)$	Maximum possible benefit return in the world at time t
β_0	Theoretical benefit threshold for the existence of populations
β_1	Theoretical benefit threshold for sustainable populations
$\underline{C_i}(t)$	Confidence vector of individual i at time t
$C_{i,S}(t)$	Individual i's confidence in their self at time t
$C_{i,C}(t)$	Individual i's confidence in their group of advisors at time t
$C_{i,E}(t)$	Individual i's confidence in their encounters at time t
C_{prt}	Cost of the child to the parent
$\mathbb{C}_i(t)$	Set of all agents who advise individual i at time t
D	Developmental period (years)
δ_{ij}	Individual i's evaluation of individual j's advice
ΔW_i	Yearly change in the wealth of individual i
$\mathbb{E}_i(t)$	Set of others that individual i encounters at time t
$\eta(a,t)$	Efficiency of resource extraction by action a at time t

f	Exponent of frequency dependency
$f_i(a)$	Number of times a is observed by individual i
$\phi_a(t)$	Relative frequency of action a at time t
G_{prt}	Gain of the parent from the child
G_j^*	Set of individuals in the age group corresponding to j'th bin
$\mathbb{G}_x$	An abstract group of individuals, x
k	The number of action Terms each year
$L_i(t)$	Yearly living cost of individual i at time t
λ	Feedback frequency, the probability of observation
M_3	Third moment of a distribution function, the skew
μ	Stochastic accident rate
$N(t)$	Population at time t
N_i	A node with index i in a generic graph
$\mathbb{N}$	The set of natural numbers
P	Parenting cost (benefit)
P_x	Probability of an exploratory action
$P_x max$	Maximum probability of exploratory actions
$\mathbb{P}$	Total amount of parental investment necessary to raise a child
$R(t)$	Resource level of the world at time t
$\underline{R}_i(t)$	Preferability ordering of actions by individual i at time t
$\underline{R}^*(t)$	Objective value ordering of actions in the world at time t
R_{max}	Maximum resource capacity of the world
$\rho(t)$	Resource r+egeneration of the world at time t
$s_i(t)$	Number of others individual i encountered up to time t

T	Council trust matrix
T_{ab}	A Cell of the council trust matrix T
$\mathbb{T}$	Time frame of relevance for frequency dependency
t_i	Current age of individual i
$\tau_{ij}(n)$	Individual i's trust in individual j after n interactions
$\mathbb{U}$	Set of all individuals
$\mathbb{U}_i$	Set of all individuals other than individual $i : \mathbb{U} - \{i\}$
W_i(t)	Accumulated of wealth of individual i at time t
x_p	Exponent representing the length of parenting

CHAPTER 1

INTRODUCTION

Humans are social creatures. They are born vulnerable, requiring the help of their parents and other benefactors to stay alive, and learn to navigate a life with boons and perils. With minimal change in our genetic makeup for millennia, we have lived in caves, forests, tribal villages, feudal kingdoms and sprawling industrial cities. We form communities regardless of the environment we inhabit or the conditions we face. Maybe the only given in all human conditions is that we are embedded in a society. In a fitting manner, our cognition necessarily has an irreducible social component. Inquiries into the nature of human minds and cognition have been central topics in philosophy and science since their dawn. Even though technological innovations and scientific breakthroughs from the recent centuries bring us closer to understanding the intricate mechanisms involved in minds, existing and competing theories about the mind are far from being established theories and more or less operate as working hypotheses to be tested. A significant part of cognitive psychology program is occupied with building and testing such hypotheses.

Societies on the other hand are usually investigated in a different manner. It is one thing, to try to understand a very complex and intractable subject that is the person, and an entirely different thing to understand large organized collectives of these persons. A society has a set of complex entities and social structures. Entities like hunting parties, workers unions, armies, states or academia are composed of and sustained by a collective of individuals, but they exhibit properties that are not intrinsic to these individuals. These entities are accompanied by particular arrangements of the natural environment such as factories, barracks or universities and operate in certain cultural settings more persistent than the individuals who learn to enact them. Scientific disciplines like social sciences or economics which simply must relate to the properties and attributes exhibited by these higher-order entities, since their explananda usually lies in the same higher-order domain, are inclined to propose correlations or even causal relations between these entities. For example, a statistical correlation between the rise in inflation and the reduction in unemployment can be used to argue that higher inflation is good for employment. This type of approach is certainly frugal and useful to make preliminary assessments but it fails to provide an explanation of why this is the case, usually prompting an inquiry into underlying components and factors for mechanistic explanations.

The problem here is that some of these underlying components typically evade the formalism and scope of the scientific or social discipline which poses the initial questions. Hence the buck tends to stop with the entities of the lowest possible order recognized by the discipline, essentially leaving the explanation hanging in mid-air. Fortunately, it is possible to go one step further. If one can provide an adequate approximation to these evasive components, these approximations can help build a foundation where the relations between higher-order entities can be expressed in a more satisfactory manner, namely through the relations between their components. This procedure has been dramatically successful for theory building in natural sciences like physics or biology, and even in interdisciplinary approaches to social sciences or economics. Yet there is a fundamental difference between theories of physical nature and theories about people. Behaviour of physical particles does not change as a result of the theories articulated about them, but behaviour of people does. If someone believes in a theory about people, their behaviour changes in a way that may vindicate the theory. Similarly if a theory about people becomes common belief in a society, the individuals act in certain ways under the assumption of the operating theory to manifest the exact higher order symptoms and relations which would justify their operating theory. This has the following implications: (1) Psychological, Sociological or Political theories can never be considered as purely descriptive beyond the point after which they start to be circulated. (2) Complementary naturalist processes of theory building and subsequent empirical validation is compromised in the domain of social sciences unless the theory building part is accompanied by its immediate empirical validation.

I do not really offer a better alternative scientific paradigm in this thesis. In fact I will fall into many of the same traps as others before me did. I will attempt to describe a phenomenon, or macro regularity if you will, visible in most human societies: the phenomenon of generations, or groups of similarly aged individuals who tend to behave in a similar fashion which is usually distinct from how the rest of the society behaves. Then, in order to articulate an explanans, I will proceed to lay a foundation consisting of the entities of lowest order that I can plausibly approximate. I will not insist on the principle of parsimony as I do not seek the simplest model with less assumptions, one that likely yields elegant analytical results. Plausibility will be much more important to me than it would be to a physicist not only because I am in the privileged position of being a person which coincides with my subject matter but also because I am responsible for the consequences of my explanations maybe more so than for their validity. As my phenomenon of interest resides at the level of societies, my responsibility will be to provide a model of societies and their constituent building blocks which are realistic enough to mitigate the form of reductionism inherent in my endeavour, yet generic enough to accommodate most existing theories about the nature of entities subject to my approximations. I will start by providing elemental depictions of these entities, intentionally elemental so as not to have a veritable mountain of my preconceptions manifest in these depictions. My primary functional unit will be a *meta-action*.

1.1 Meta-actions

Actions are what people do as opposed to what happens to them. They are intentional, that is to say, conforming to some interpretation of intention. But most actions understood as such, are still truly insignificant to serve as functional explanatory units. Taking strolls, shopping for vegetables and cooking dinners are such intentional actions. While insignificant actions may still have spectacular causal implications, it is not in their nature to consistently do so. On the other hand, deciding to adopt a healthier lifestyle has those implications, it makes people take strolls, shop for vegetables and cook dinners. It is the type of mental action which forges the intentions that are to accompany these further, lesser actions. In turn, such actions as cooking dinners prompt even lesser actions like peeling potatoes or setting up tables.

In short, types of actions form a hierarchy in terms of their intrinsic causal natures. However, this is a deeply subjective hierarchy since the causal effects of actions can only manifest in conformity to the conceptions of the person who is taking these actions. Furthermore it must also conform to de facto opportunities available to the individual, shopping for vegetables is not an option in a jungle.

By a meta-action, I refer to the type of individual action which ranks highest in the personal/external causal hierarchy in a given time frame. This means that my definition of a meta-action is in fact a family of definitions: Taking a stroll might be one such action in relation to a day, whereas in relation to a decade, it is insignificant. Significant meta-actions in relation to a decade, might include enrolling in a university or starting up a business. Once a time frame is fixed, one can use a simple linguistic rule of thumb: Meta-actions are those that have to be chosen from among alternatives, while a multitude of lesser actions can be performed together or in sequence. Meta-actions also do not translate consistently into particular actions because they may manifest as very different actions as enacted by different individuals and under different circumstances. In short, they resemble formations of intention more than they resemble any sort of action. Keeping this distinction in mind, from here onward, the term *actions* will be used to mean meta-actions.

Actions of individuals in a society are guided by their understanding of the world. There may be occasions where certain biological factors or tendencies acquired from our evolutionary past play crucial roles to modulate our behaviour, yet ultimately how we perceive the world is the most important determinant. While this understanding to some extent is the result of our past experiences, as social agents we also engage in acts directed towards knowledge or opinion acquisition. We turn to others we trust for contextual advice meanwhile passively receiving unexpected advice from strangers. Social problem solving allows us to benefit from other individuals' experiences that relate to situations prompting reactions or contexts in which actions have particular consequences. Trust in others is necessary for this to function. This is most apparent for babies. As people age, they make progressively more informed and confident choices but they still require the advices of others. An individual's understanding of the world may be important, but so is the individual's perception of others who understand the world differently. Information relayed to an individual by others must be judged by the individual before he/she acts on it. Since the individual can act on such information, this means that social epistemology of the world knowledge is as important as the individuals' world knowledge for understanding the causes of actions.

Individuals do not perform actions in a void and the consequences of choices in a changing world are not set in stone. Settings where consequences arise from the laws of physics may be predictable, but these settings are exceptionally rare. Instead, the resolution of most situations are affected by other external dynamics of varying time-scales or uncontrollable factors. Therefore a dated experience may be unhelpful in a situation resembling the original experience. And it is not only the world that changes: In time, the children develop into adults, lose and gain certain capacities and skills, are treated differently by society, and their actions have different consequences. Even if we were to assume that the cognitive apparatus itself is capable of rationally deducting these consequences in a timely manner, limitations on the availability of information and the limitations of perceptive capabilities involved in the extraction of the relevant information from the world compels us to assume that humans act in ways that are less than rational. This is not to say that we act without reason or rationale, but to impress that the ordinary human condition is quite far from the classical conception of a strictly rational agent. Rational or not, there are reasons to why a person acts in a certain way and these reasons are contained in the person and his/her environment. The environment understood as the medium of individuals' actions, is the world containing not only objects and systems of a physical nature but also rules, norms and social systems structured by a collective of other individuals. The most important thing to impress about the world at this point is that, it changes.

1.2 Generations

Generational differences are observed in almost any specific human society. And there are many potential explanations of the divergence of individuals who are born in a particular era from other individuals who were born before them; maybe they have cars, computers, better nutrition, or maybe the war is over. Whatever the set of reasons, those who have experienced a particular change in the world, develop a stance towards the present circumstances which is different than of those who are born into them. People whose understanding of the world evolved under different circumstances adapt to the present circumstances. But while those who are born into them regard the current circumstances as given, the generations that came before them experience having taken part in its shaping. Whether they were instrumental or not in this shaping, living through a change is itself a very good reason to have a distinct mode of operation regarding the present circumstances.

When people get older they still have in them, the experience of being younger via their memories and habits and they retain the experience of their interactions with others and with the world as it were; only that, some experience they have is no longer particularly useful for them or some previously unhelpful information becomes relevant. In any case, it is undeniable that individuals' understanding of the world is directly influenced by the historical conditions setting the medium for their actions and experiences.

As a rule, societies heterogeneously consist of people from all ages with diverse qualities. Recent part of the last century endowed us with the ability to observe and catalogue generational differences in opinions, policy choices and perspectives of life from a significantly more representative sample of the reality than previously possible. I will not list all the documented instances of generational differences ranging from differences in psychological constitution such as tendency of depression, stress management or reaction to conflict, to ideological differences such as degree of materialism or pragmatism. I am much more interested in a general understanding of generational differentiation than in particularist investigations of certain generational differences. What matters to me at this point is that even though it is a matter of debate whether all these differences have always existed but become more visible recently or that they are getting more pronounced as the world changes ever faster, the concept of generations remains as an important tool in many social explanations including those regarding the more critical aspects of societies such as the political or moral choices of their members.

Curiously, it is not at all clear whether a society in a given time frame or at the onset of an important change, will manifest systematic generational differences in behaviour, perspectives or norms. The singular fact that we can observe some of them at some times, does not necessarily explain away the fact that at some other times, we can not. Observed generational differences can be causally explained in retrospect with relative ease, but could they be predicted beforehand? And maybe more importantly, given that such differences manifested, what can we infer from these differences regarding the society and the world in which it is situated? In this thesis I will try to give provisional answers to these questions by providing an account of generational differentiation and its sustainment by proposing a micro-foundation of social relational mechanisms.

CHAPTER 2

BACKGROUND AND LITERATURE

This chapter aims to bridge the conceptual and methodological foundations of this thesis to some of the historical and contemporary works of philosophy and science. Unfortunately, because of the numerousness of these concepts and their inherently complex natures spawning a broad spectrum of interpretations, I will not be able to lay down a comprehensive corpus of such previous studies. Instead, I will be generally describing some of the work that I find most relevant to the ideas and instruments I will be employing.

2.1 Sociological theories

Societies have always inspired philosophers. This fact is evident from the variety of social philosophies put forward through recorded history. Yet, it was a number of fairly recent paradigmatic changes in the sciences which finally sanctioned the discussion of a science of societies. Sometimes regarded as the inaugural philosopher of social science, Auguste Comte (1853) described the empirical foundations of sciences and posited a hierarchy of sciences in increasing complexity, featuring a then-yet-unborn social science at the top of this hierarchy. From empiricist roots and armed with a functionalist methodology, Karl Marx (1867) and Émile Durkheim (1893) laid the foundations for this new science which came to be known as sociology. The emphasis on the social facts or existing structures and the proposition that these are the prime causes of social phenomena seen in these thinkers was later challenged by Max Weber (1922) who proposed that social phenomena must be explained by showing how they result from individual actions. Giddens (1984) in this theory of structuration, described a dual nature for structures as both causes and outcomes as embedded in agents. The methodological approach of this thesis will be more or less compatible with the fundamental tenets of structural individualism, yet some considerations regarding the social structures will be borrowed from Giddens.

2.1.1 Generations theories

Generations have received a fair amount of scholarly interest. Yet, once one eliminates the informal references to this concept and its instrumental use in explanations, as well as the numerous critiques to these uses, one is left with a relatively small number of theories attempting to formalize what they are and how they matter. In his investigation of suicide, Durkheim (1897) developed his concept of 'anomie' to describe a particular type of individual disconnection from the society. He also noted of the feature of recurrence of generations, "Each new generation is reared by its predecessor; the latter must therefore improve in order to improve its successor. The movement is circular." (Durkheim, 1897). The proposition that generations have certain transformative powers is later reiterated in the analytical tradition of social sciences by Mannheim (1927) who considered it to be one of the ultimate factors of human existence, "(...)contributing to the dynamic of historical development." (Mannheim, 1927). In a sense, all generations theories can be seen as attempts to flesh out this contribution. Distinctly phenomenological account from Ortega (1956) conceived generations as contemporaries in the spatio-temporal human experience where agedness signifies the manifestation of time in the reality of human life and a succession of generations and their coexistence is the unity of the past and the present. From the ideas of these thinkers and of others who are not mentioned here, two crucial aspects of generations appear to be central to generations theories: (1) that they involve some kind of circularity and (2) that they have certain transformative powers in a society.

2.1.2 Agent-based modeling and generative models

Agent based methods are particularly suitable for modeling human societies, as well as any system which also consists of autonomous and interacting agents. Earlier examples with cellular automata such as Conway's *Game of Life* (Gardner, 1970) successfully demonstrated the power of this methodology in generating systems capable of manifesting high level emergent characteristics from the collective behaviour of automata. It was not long before the first generation of artificial societies started to surface. In his models of segregation dynamics, Schelling (1971) employed them to investigate the results of the discriminatory choices of individuals in a spatial world. Axelrod (1997) used a grid model with cultural interaction dynamics incorporating homophily. Aspatial variants of this model cover a wide range of interaction topologies (Centola, 2007). As computer systems became widely available, it became feasible to simulate models with increasing agent complexity. In *Sugarscape* (Epstein, 1996), agents are capable of a variety of distinct interactions with the environment and the other agents. In *RebeLand* (Cioffi-Revilla, 2016), vastly different actors such as civilians, cities and administrations in a complex scenario are modeled as agents.

This thesis also makes use of some concepts borrowed from game theory such as Nash Equilibria (Nash, 1948), the stable state of a system of interacting participants in which no participant can gain from a unilateral change of strategy, and from complex dynamical systems such as self organized criticality (Bak and Paczuski, 1995). Formation of social norms is also a critical component of this study. A social norm can emerge from the norm-inducing behaviour of individuals or might be imposed externally. I will be focusing on the former type of social norms in this thesis. This type of norms have attracted many functional explanations. Evolution of norms is studied extensively in game theoretic contexts like simple coordination games by Blume (1993) and Young (1998) where norms are understood to be clusters of a strategy in space and in formation of opinions and their dynamics (Mas et. al., 2010). Epstein (2001) illustrates an adaptive model of norm fitting in the ring topology. In general, many models of this family utilize sociological or psychological tendencies such as homophily, striving for uniqueness or even norm fitting as ‘given’ (Binmore, 2010). I will try to avoid imposing these types of tendencies on the individuals and will not specify the nature of their norm-inducing interactions. The epistemological implications of social simulations in theory building and testing requires careful deliberation as discussed by Conte (2009).

2.2 Decision theory

Explanations of the operation of groups or societies are naturally related to the explanations of the operation of individual minds. Yet, people’s perception of the working of minds is also a strong factor. Heider (1958) impresses the importance of ‘naive’ psychological theories in explanation of social phenomena. For the purpose of this study, the question of how minds work will be secondary to the question of how people act. The oldest and still the most common framework to make sense of aggregate behaviour of people using operating assumptions about the individuals is *rational choice theory* whose many central ideas can be traced back to Adam Smith (1776). Modern incarnations of this theory which do not insist on strict rationality have a very simple requirement: that the decision makers’ preferences must be complete, meaning that all their options are pairwise comparable and that these comparisons are transitive. How these comparisons are made (descriptively) or should be made (prescriptively) is the topic of various utility functions which normally supplement the rational choice theory with comparable probabilistic expectations or weights for the outcomes of chooser’s options. Most famous of the contemporary descriptive utility theories is *prospect theory* by Kahneman and Tversky (1992) where expected utility function takes into account the asymmetry in real subjects’ evaluations of prospects and risks.

Rational choice theory describes the decision making process of a rational agent as a single-step operation which consists of the maximization of a well-defined utility function. In consideration of the contrasting view that all the criteria used by a rational decision maker can not be translated into the maximization of a utility function, this thesis breaks down the decision making process of individuals operationally into two stages.

Within each individual we model a set of competing tendencies which manifest as distinct decision strategies. These are autonomous, social, follower and exploratory tendencies which will be described in detail in section 4.2.3. At each moment the decision maker finds himself afflicted by a certain tendency and employs the corresponding utility function. While all of these functions result in verifiably rational choice theories when singled out, overall deciding behaviour of the individuals in the model can not be characterized as complying with rational choice theory.

2.3 Trust

Earlier insights into the studies of trust came from the perspective of game theory (Deutsch, 1958). As trust is construed as both a psychological phenomenon and a property of relations of organizational or institutional entities, there is quite a diverse literature into the relation between competence and trust in various contexts such as communication (Giffin, 1967), participative decision strategies (Rosen & Jerdee, 1977), collaborative actions in game theory (Good, 1988) or management of organizations (Mishra, 1996). A relational conception of trust is investigated in the presence of third party observers (Burt and Knez, 1995) and with relations that are typically asymmetrical in power such as organizational hierarchies (Kramer, 1996). Context dependency of trust is discussed by Hardin (2002).

After the internet revolution, a form of operational trust became a tangible metric and commodity because the functioning of online multi-agent systems required a protocol of trust between them. In large-scale distributed systems of electronic entities, trust is generally understood to be more about honesty, as the estimation of the capacity of these systems is rather trivial: It reduces to their ability to offer the services that they are specified or promise to give, in contrast with real human beings. It is worthwhile to note that even understood as such, trust still has discernible components in system-level trust and individual-level trust (Ramchurn, 2004). This conception of the multiple modes of trust becomes even clearer when applied to human societies where varieties of interpersonal trust and trust in institutions are separate interacting processes (Khodyakov, 2007).

The notion of *trust* in this thesis is confined to be a relational entity between two individuals affected by the actions of both individuals. This entity is born out of the family structure which embeds all individuals, and functions to estimate the competence of others in the special context of advising.

Finally, agent based models commonly feature age or generation as variables denoting the persistence of agents or as timestamps, and this special terminology obscures the literature on the actual phenomena of ages and generations. Nevertheless, my survey on the topic and the methodology seems to imply that agent based methods literature lacks a study on age and generation effects.

CHAPTER 3

PROBLEM STATEMENT

The aim of this thesis is to model social dynamics of trust and decision making in order to investigate their correlation with age, providing a humble contribution to partially filling the gap in the literature. Our study involves an investigation of the trust relation between age groups under different conditions and the circumstances that enable the emergence of generation gaps for which a formalism is proposed. In order to compose a generative society model capable of manifesting generational differences by discernible and tractable mechanisms, a number of simplifying assumptions are made:

(1) It can be said that people strive for different things. However in this model, individuals will only be interested in a single abstract currency: *Benefit*. This benefit plays the role of an objective utility. A considerably more complex model may incorporate multiple subjective utilitarian functions but such a nuanced approach will not be used in the scope of this thesis. In short, intrinsic value of actions will be considered the same for all individuals.

(2) Trust is a complex social stance involving context-dependent judgment of competence, psychological affinity and the guessing of intentions. There are also forms of non-interpersonal trust in systems or institutions. However, trust in this thesis will be modeled to be generic trust in another agent's competence embodied by the individual's counseling relation. Luckily, underlying components of the trust in competence are usually general skills and capacities that transfer well to other contexts. Psychological dimension of trust will be partially represented by the relational aspect of connections. However, agents of this simulation will always be honest towards each other.

(3) Most human actions are not isolated performances. Actions of individuals usually serve long-term goals and achieving long-term goals involves deliberation over a sequence of actions. With the presence of goals and plans, human actions can only be understood in the light of their intentions. In this model, the word *action* will be used to denote the higher level actions that can be assumed to be more or less isolated, such as the conception of a long-term goal. Therefore only a few actions will be taken by the individuals annually, representing decisions that determine or modulate the rest of their actions in that period.

(4) Some actions, particularly of collaborating or competing individuals, directly affect the world conditions. Therefore some aspects of the world conditions are at least weakly coupled to the actions of individuals. While the model partially incorporates this effect in the form of shared resources and *frequency dependency*, a notable section of such actions are not within the scope of this thesis. To justify this, modeled society is assumed to be benign and unrevolutionary.

(5) Apart from a small number of communities worthy of anthropological interest, societies are never completely isolated. There is always a certain flux of population resulting from migrations with its implications to demographical structure and cultural composition. For different societies this effect varies in strength. While the model itself can be modified to incorporate this fact, in this thesis, societies will be assumed to be isolated i.e. closed in population dynamics.

(6) Even though parenting is quite important to the working of the model, there will not be genders or an adequately complex mating behaviour. However there will be a detailed maturation process as warranted. Babies will inherit some characteristics from their parents and their world models will initially be shaped by them. They will also be situated in their parents' network of knowledge. During a development period of offline learning, they will be simulating decisions and interacting with parents, strengthening their imprinting while transitioning smoothly to adulthood.

(7) With respect to the elemental action of the social practice in the model, namely asking for advice, no spatial world is necessary. Our accumulated arsenal of distant communication methods diminishes the effect of physical space in advice seeking actions. Thus there will be no attempt to simulate the physical space, albeit some aspects of spatial affinity will be partially simulated in community formation mechanism.

CHAPTER 4

PROPOSED MODEL

We introduce an agent based model of a trust network co-evolving with a dynamic multi-generation population in a benign society living in a fixed environment with limited resource supply. This population is assumed to be under pressure, incurring costs of life and individuals must act wisely in order to survive and reproduce. Their actions result in them obtaining benefit, a single resource representing their wealth and health. Our model is aspatial, meaning that we assume that the physical location of individuals is not a factor. Each year is divided into k discrete action terms in which the individuals must perform an action. Events pertaining to the population dynamics are handled at the end of each year. Actions of individuals are synchronized i.e. they are assumed to be performed at the same time. The model consists of the interactions of dynamic systems that model the natural environment and the individuals living in it. These coupled systems will be denoted as the world and a society consisting of a connected network of individuals. Hence the parameters of the model can be listed under these two sections.

4.1 The world

The individuals are assumed to be situated in an environment modeled by the world which represents the medium where the resources reside to be used by the individuals. Individuals obtain benefit as outcome of their actions and the world model dictates the amount of benefit provided by the individuals' actions. The state of the world at any given time instance is defined by:

(i) A benefit pay-off function $B(a,t)$, which determines the nominal outcomes of actions which signify the inherent values of these actions,

(ii) The world's resource level which affects the efficiency of individuals' actions as they harvest the resources to obtain benefit,

(iii) The frequency recording of performed actions $\phi_a(t)$ which also affects the efficiency of actions according to world-specific schemes

Relative nominal benefits of actions, $B(a)$ are sampled uniformly from the cumulative β-distribution and normalized such that the nominally best action yields B_{max} benefit. $B(a)$ represents the inherent value of action a. Individual's gains or actualized outcomes of performed actions, $B^*(a,t)$ are scaled according to the efficiency function, $\eta(a,t)$:

$$B^*(a,t) = \eta(a,t) \cdot B(a) \tag{4.1}$$

The world has a limited pool of resources, $R(t)$, which regenerates at a rate $\rho(t)$, up to a fixed resource capacity (R_{max}). By taking actions, individuals harvest some of the world's resources into personal benefit. Historical prevalence of an action a up to and including time t is denoted by $\phi_a(t)$. Frequencies of actions are calculated such that the effect of actions performed longer time ago is exponentially weaker than the effect of those performed recently. Efficiency function η can be written as:

$$\eta(a,t) = \frac{R(t)}{R_{max}} \cdot \left(\frac{\phi_a(t)}{\bar{\phi}(t)}\right)^f \tag{4.2}$$

where $\bar{\phi}(t)$ is the average frequency of actions and parameter f is the *frequency dependency coefficient* which controls the nature of frequency dependency. Since the resources are shared, outcome of an individual's action is already affected by the actions of the rest of the society, but frequency dependency imposes additional dependence on the actions of others.

We will employ an abstract categorization corresponding to qualitatively different types of situations denoted by *action domains*. An action domain is called neutral if there is a fixed order of the benefit returns corresponding to available actions, characterized by many real life decisions that contain objectively better or worse choices. This corresponds to the case $f = 0$. In contrast other domains are past-dependent in which the outcome of an action is affected by past actions by individuals in a given historical time frame. If there are too many Chinese restaurants in a neighborhood, an entrepreneur knows better to not invest in another, this is an example of a domain with *negative frequency dependency (NFD)* where $f < 0$. Similarly the domain of *positive frequency dependency (PFD)* is characterized by actions whose outcomes are positively affected by their prevalence such as driving on the right side of the road, in this case $f > 0$. Absolute value $|f|$ characterizes the strength of frequency dependency.

4.2 Individuals

The world is inhabited by a dynamic population consisting of individuals. Individuals must annually perform k actions after which they receive the corresponding benefit determined by the world state. Before every decision, the individual attempts to get advice from a select subset of the others he/she knows or acquaintances denoted as their *council*. Individuals' social networks containing these acquaintances grow throughout their lives. This happens because at each action term, there is a chance for them to meet another individual that they do not know. We will call this other individual, a stranger. The rate with which the individuals encounter others will be determined by the parameter *encounter period*, denoting how many action-terms must pass in order for the individual to encounter a stranger. Individual's network formation is probabilistic and is defined by two parameters: *Social conservatism*, denotes the probability that the individual encounters one of his existing contacts instead of a stranger, and *community exploration* which is the probability that the individual encounters one of its contacts' contacts as the stranger. For simplicity, we will assume that these probabilities are the same for all individuals and that they are fixed.

4.2.1 Life and death

Every year, individuals' accumulated benefits or wealth will be drained by a living cost. For an individual i, the living cost $L_i(t)$ will be composed of a base cost and an age dependent cost, increasing linearly with individual's age, t_i. We will assume that a portion of an individual's wealth is in the form of their physical fitness or health. Health of an individual i is initially small, denoted by *baby immunity*, increases linearly until the maturation age of 18 to a maximum health called *maximum fitness*, stays constant until the age of 55 and declines from then on until a *fragile age* where the physical fitness of the individual becomes minimal. Health function of an individual as a function of his/her age is graphically represented in Figure 1.

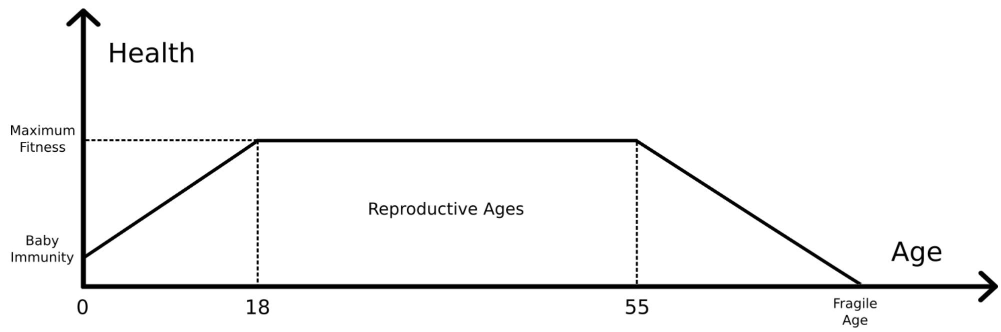

Figure 1. Health of an individual as a function of its age

Even though they are genderless, single individuals try to mate between the ages 18 and 55. When they do, they include their spouses in their networks. Once a year, couples consider procreation in the following manner: Each prospective parent considers their current economic aspects and projects their average income, living costs, and parenting costs D years into the future, where D is the development period for all children. If the prospective parents predict themselves to stay alive in this period, they decide to have a baby. If both partners agree, they procreate. If only one partner does, the couple evenly split their material wealth, which is the amount of wealth that is not part of their health, and wait for the next year to reconsider.

Parenting entails a wealth transfer scheme between a child and their parents. This process is controlled by the parameters P and x_p. After every action, the child transfers a portion of the benefit resulting from its action as the gain of the parent, $G_{prt}(t_c)$ and is reimbursed by its parents by the cost $C_{prt}(t_c)$. Therefore the true cost of parenting as a function of the child's age can be given as:

$$C_{prt}(t_c) - G_{prt}(t_c) = P \cdot e^{-x_p t_c} - B^*(a_c) \cdot e^{-x_p t_c} \tag{4.3}$$

where $B^*(a_c)$ is the benefit return of the latest action performed by the child (a_c) who is t_c years old. The effect is the following: Actions of babies have minimal effect on their wealth and they are sustained mainly by the wealth transfers from their parents. In the typical case where $P \geq B^*(a)$, parents use their accumulated wealth to improve the child's well-being until $e^{-x_p t_c}$ becomes insignificant as the child grows. In parallel, the actions of the child gain importance for its well-being as the child grows. Development period D is chosen such that by the end of this time, most of the benefit attained by the child comes as consequence to its own actions. Parents also automatically become the child's first council guiding these actions. Existing children are important factors in parents' child making decisions as the wealth transfer to the child, or the cost of parenting (C_{prt}) is an important item in families' wealth projections, especially when their children are still young. Figure 2 shows the parenting cost for an individual as a function of the child's age.

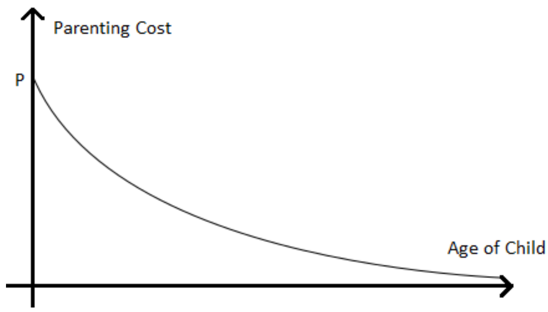

Figure 2. Parenting cost as a function of the child's age shows exponential decay.

Individuals die as a result of accidents. Every year, a fraction denoted by *stochastic accident rate* of the existing population has accidents. Impact of each accident is randomly generated from a geometric distribution which can attain a fixed maximum impact. If the impact of the accident is higher than the individual's health, the accident results in death. Otherwise, the individual gradually recuperates from the accident using material wealth to replenish his/her health. Since after a certain age, health of an individual reduces to zero, any and all accidents result in certain death. When a death occurs, the wealth of the individual designated as its health returns to the world and its material wealth is redistributed to his/her spouse and children. Remaining spouse is free to mate again. These endogenous mechanics of reproduction and death define the population dynamics of the society.

4.2.2 Knowledge and trust

Each individual has a world model ($\hat{b}_i$) composed of the expected benefit outcomes of actions. As babies, individuals inherit a blend of their parents' world models associated with a certain strength denoted by *fidelity to parent model*. After each action, individuals receive information about the actual benefit returns of the actions in the world either via the results of their own actions or via feedbacks given by their advisees after their actions. Individuals update their world models with a frequentist paradigm i.e. individual i's benefit expectation of an action, $b_i(a)$, will be the average of all observed benefit returns including observations inherited from its parents. After an estimate is given by a council member or stranger, and an action is taken, advisers have a chance to be informed of the resolution of situation with a probability λ, called the *feedback frequency* and update their world models. This probability simulates the combined effects of the observation of resolution by the adviser and the feedback given by the action-taker.

When an individual gives advice, there is a probability P_ϵ that each benefit estimate provided can deviate from the adviser's world model by a certain fraction

d_ϵ denoting *communication noise* which expresses the effect of a misinterpretation, exaggeration or understatement by either party in the communication. After an action is performed and some benefit is received, the individual evaluates the recent estimates provided by others to discern between good and bad ones. Goodness of an estimate is given by an *advice evaluation function*, δ:

$$\delta_{ij} = \left(1 - \frac{|B^*(a) - b_j^*(a)|}{B^*(a)}\right)^d \tag{4.4}$$

where $b_j^*(a)$ is the reported estimate for the outcome of action a by individual j and d is called the *trust dispersion coefficient* which serves to amplify the variation between interpersonal trust towards different individuals. Individuals retain an assessment of reliability for all their contacts in the form of interpersonal trust (τ_{ij}), a quantitative measure of expected reliability. Even though this measure forms the foundation of the trust relation in the model, it is not a direct indicator. With the initial values $\tau_{ij}(0) = 0$, individual i's interpersonal trust in individual j after interaction n can be incrementally defined as follows:

$$\tau_{ij}(n+1) = \frac{n \cdot \tau_{ij}(n) + \delta_{ij}(n+1)}{n+1} \tag{4.5}$$

A certain number of acquaintances that the individual trusts most, is called individual's council. We define the trust relation between two individuals only when the trusted individual is in the council of the trustor. Note that, by this relational account of trust, a baby only trusts his/her parents since they constitute the council regardless of the baby's interpersonal trust in them.

4.2.3 Decision tendencies

At each moment the individual is under the influence of a particular tendency which modulates its decision process. The different tendencies which afflict the individuals compete within each individual depending on the individual's relative confidence in three abstract entities: (1) their own world models, (2) advices from their council and (3) an arbitrary encounter. The entity that provides the predictions with least error, grows in reliability. Estimates in an ϵ-neighborhood of the best prediction are considered equally useful. Confidence in an entity is the ratio of useful estimates to all estimates provided by that entity. For an individual i, these relative confidences are expressed by a confidence vector:

$$\underline{C_i}(t) = \big(C_{i,S}(t), C_{i,C}(t), C_{i,E}(t)\big) \tag{4.6}$$

The decision procedure to select the action to be performed involves forming a *utility function* according to the dominant tendency influencing the individual. The action with the highest expectation of benefit in the utility function is chosen to be performed. Depending on the composition of the confidence vector at a given time or the dominant tendency, individuals possibly act in three different manners corresponding to distinct decision strategies.

(i) Individuals who have more confidence in their own world models decide their course of action by themselves. Individual's utility function for these decisions is his/her own world model. We will call this the *autonomous* decision strategy.

(ii) Individuals who have more confidence in their councils, form a consensus model from the advices of their councils using their individual reliability assessments (τ) as weights and use this consensus model as the utility function. We will call this the *social* decision strategy.

(iii) Individuals who have more confidence in arbitrary encounters act according to the advice they received from their latest encounter. They take this advice as their utility function. We will call this the *follower* decision strategy.

In addition to these competing tendencies, we also employ an *exploratory tendency* which under certain conditions steps in stochastically resulting in another utility function. When deciding under the influence of exploratory tendency, the individual tries the action least known by him instead. With a probability P_x, a function of the change in individual's wealth during the last year, the individual i chooses the action a, randomly selected from among the actions with minimum *sample size*, $f_i(a)$ to perform. Individuals with an upwards trend in well being tend to explore more and individuals with declining well being tend to explore less. P_x as a function of ΔW is depicted in Figure 3.

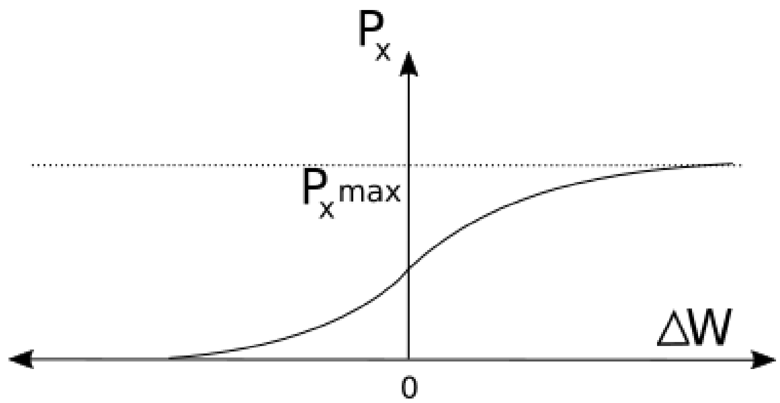

Figure 3. Exploration probability of an individual depending on the change of wealth within the last year denoted by ΔW.

4.3 Simulation of the model

The simulation of the proposed model is implemented on Unity 5.3.5f Free Edition with C# language using no external libraries. Every run of the simulation is repeated with sufficiently many random number seeds and logged accordingly. Tools required for any analyses in this thesis are also produced with the same platform and language. Adequacy of random number generators are tested to comply with the statistical expectations for uniform and geometric distributions.

The initial population called *ancestors* is created with ages uniformly distributed over the age spectrum. They are provided with an amount of wealth proportional to their health. They are randomly assigned initial councils, and they know no other individuals except those who are already in their councils. The world starts with the maximum amount of resources it can hold. The simulation is assumed to be in an initial transient phase until a number of generations have been endogeneously produced because the first generation of endogenously produced individuals are still raised and taught by the created population and second generation is raised by the generation who is raised by the created population, and so on. This means that the transient phase ends when the effect of the creation can be assumed to be insignificant in the population. All analyses are conducted well after this phase ends.

Figure 4 shows a functional diagram of the agent of individual summarizing its behaviour. Individuals complete k action cycles before performing certain actions that can be done once every year, such as mating and reproduction. Advising behaviour and feedbacks to the individual are not shown in this chart because they are considered passive reactions to some other individual's consulting behaviour. In the terminology of agent based methodologies, the world is also an agent which reacts independently to the actions of Individuals. Even though the model has a single World in the thesis, it can be expanded by a number of connected worlds representing neighboring environments.

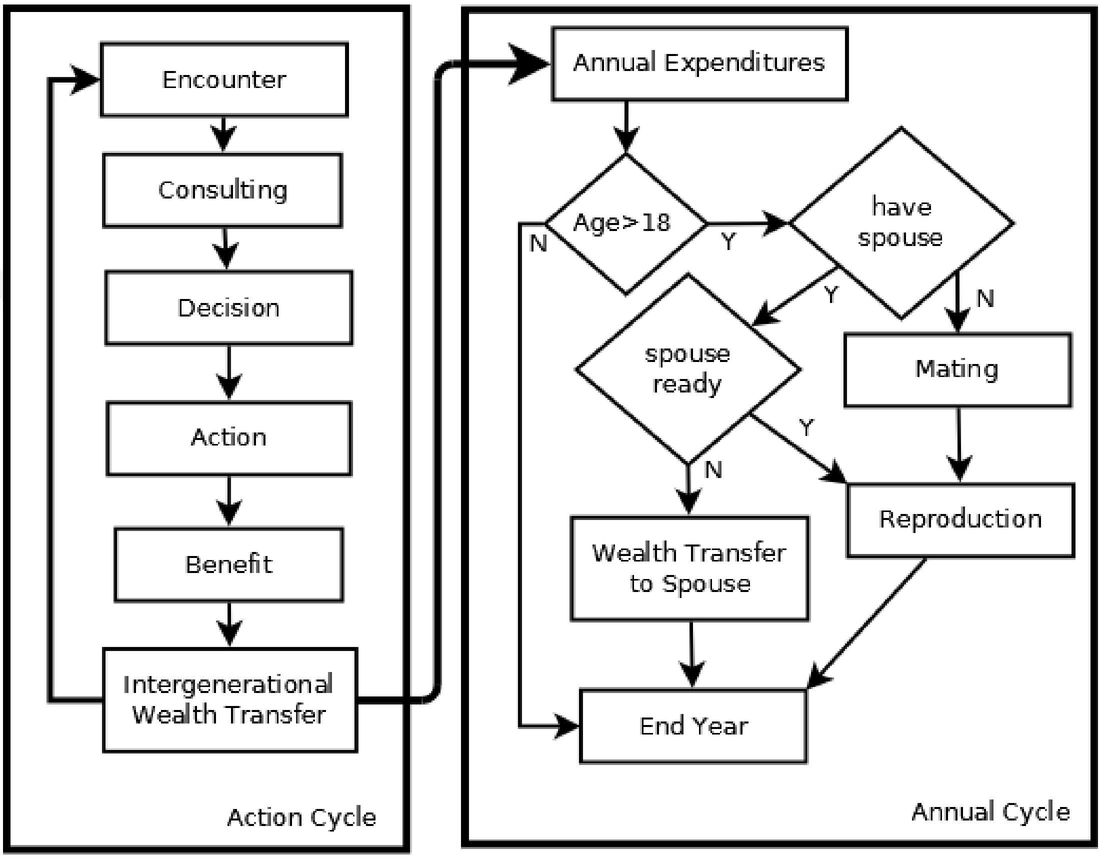

Figure 4. Functional flow chart of an individual agent in the simulation

CHAPTER 5

PRELIMINARY EVALUATION OF THE MODEL

Most of the parameters of the model are tuned with the main concern of providing a tenable account for some human facts, environmental properties etc. and they do not contribute to the analyses to be made in this chapter. Further discussion about the justification of these values and the model's sensitivity to them can be found in Appendix A. For the rest of the thesis, following parameter values can be assumed unless stated otherwise:

- Ancestor population : 400
- World : actions = 10 , maximum benefit = 2, action terms = 5
- Network : council size = 7, encounter period = 2
- Network formation : P(conservatism) = 0.4, P(community exploration) = 0.9
- Living costs : base cost = 1.2 , cumulative cost = 0.08
- Health : maximum fitness = 25, baby immunity = 0.3, fragile age = 75
- Stochastic accident rate : 0.05
- Accident impact : maximum = 50, geometric distribution probability = 0.15
- Reproduction : age Interval = [18-55] , fertility = 0.8
- Parenting : cost = 1.2 , decay exponent = 0.1
- Fidelity to parent model = 10
- Trust dispersion coefficient : 2.5

- Communication noise : probability = 0.15, maximum distortion = 0.1
- Exploration : max frequency = 0.1 , K = 2
- Inheritance of wealth : efficiency = 1, spouse = 0.5 , children = 0.5
- Discrimination ϵ for decision strategies : 0.2

These settings allow the individuals a maximum life length of approximately 100 years when the conditions are ideal. The actions available in the world provide sufficient benefit for the population to be sustained. The relation between world benefit levels and sustainability of populations is described in Appendix B.

5.1 Evaluation of qualitative plausibility

As noted before, parameters of the model are chosen and tuned to reflect a sensible description of individuals. But before moving on to the analysis, it is perhaps best to also assess the plausibility of the resulting model in terms of the middle level regularities it exhibits. The concurrence between these emergent regularities and the empirical data, serves as a supporting argument for the plausibility of the model. A world characterized by the neutral domain i.e. without frequency dependency is used for the rest of this chapter.

5.1.1 Age demographics

In this model, we are interested in a realistic population dynamics that also results in sensible distributions of age. Traditionally, these distributions are displayed in what is known as population pyramids. Population pyramids also account for sex differences in age group populations but these are minor differences except under special conditions like war and the most overt difference is observed in the old ages due to better longevity of females. As the individuals in our model have no gender, we would expect our age distributions to resemble real life age distributions if we are to disregard these gender differences. This is what we found, as summarized in the Figure 5.

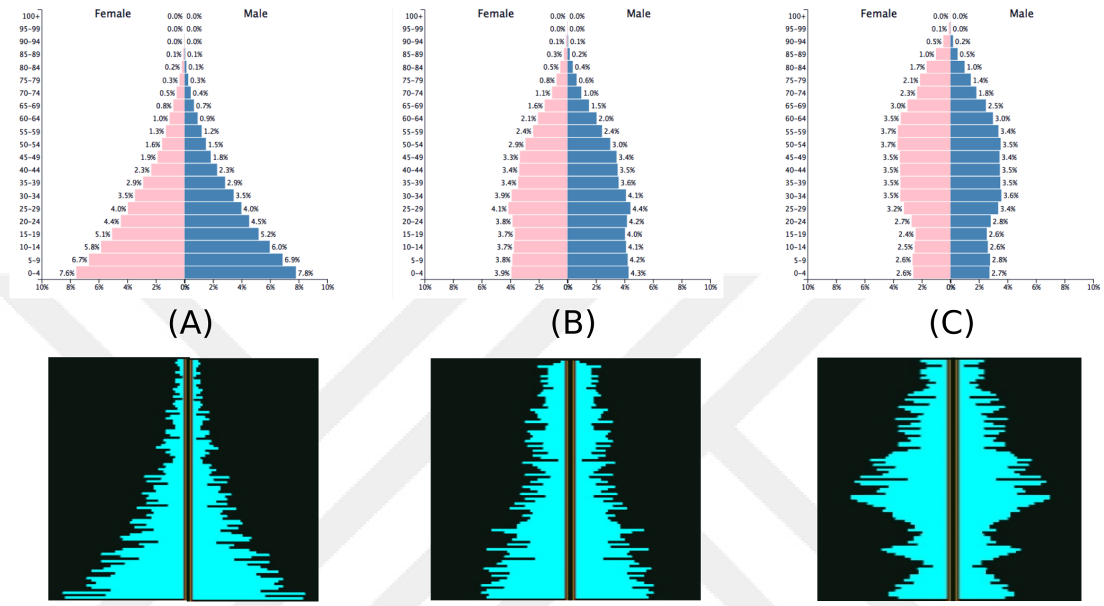

Figure 5. Above are, 2017 age distributions of Africa (A), Asia (B) and Europe (C) according to United Nations Department of Economic and Social Affairs, Population Division (https://esa.un.org/unpd/wpp/Graphs/DemographicProfiles/). Below them are some age distributions from the simulation extracted during periods of growth, equilibrium and shrink. Distributions from the simulation are duplicated to match gendered population pyramids

Population pyramids of continents instead of countries are selected for comparison because the impact of intercontinental migration is weaker than the impact of migration between countries. The fact that empirical data of the age demographics looks smoother can be attributed to a number of reasons: (1) Populations in the simulation are typically in the order of tens of thousands while the populations of continents are in the order of millions or even billions. Low populations are more affected by stochastic variations. (2) Empirical data features 5-year bins resulting in a smoother progression of histograms. We refrained from this since it would amount to artificially improving our data. (3) In our simulation, time is discrete. A suitable analogy would be as follows: Every individual in the simulation is born on the same day of the year. Whereas in the real world, depending on the date of the census, some of the individuals would be represented as one year older or younger contributing to the smoothing effect. (4) Again as a result of discrete time, feedback of the resource economy to newly born is delayed for one year in the simulation, where this is a continuous dynamics in the real world. If the world conditions amount to a severe resource crisis or some other influential factor in reproductive behaviour, real people will not wait until the next year to update their dispositions.

5.1.2 Networks and trust

A society is more than a set of individuals and some characteristics of the society manifest over the relations between these individuals. So the network structure imposed by these relations is important to us. In the model, we can talk about two types of binary directed relations between individuals.

(i) Acquaintance relation between individual i and individual j, means that individual i knows individual j. This means that at some point, individual j has advised individual i. Initially the child only knows its parents and once an Acquaintance relation is established, it is fixed until one of the individuals in the relation dies. Except for this case, the number of others an individual knows, or the size of the social network of the individual increases over his/her lifetime with a rate that is inversely proportional to choice of encounter period used in the simulation.

(ii) Council relation between individual i and individual j entails that individual j currently advises individual i, meaning that individual i considers individual j to be one of the most accurate estimators of the results of its actions. Individuals can change their councils over their lifetimes because when their interpersonal trust in a council member decreases, they replace them with the most trusted acquaintance outside the council. The size of the council always remains less than a fixed size denoted by *council size*.

Small world network is the name given to the type of networks encountered in many real life emergent networks, particularly in human societies. A small world network can be characterized by having a smaller network diameter and more clustering than a random network of the equivalent size and out-degree. In our social network, the out-degrees of nodes are not uniform so our random network will instead have the same out-degree distribution. Figure 6 shows an arbitrary node and its out-degree in a directed network.

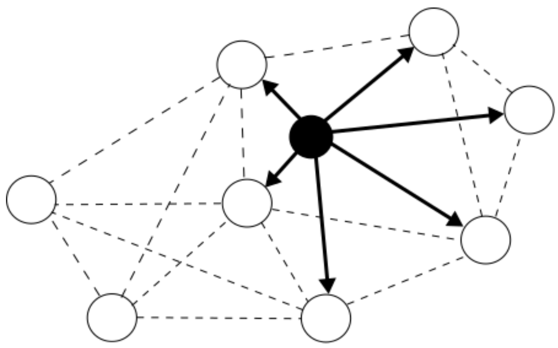

Figure 6. Example of a node in a directed network over a binary relation. The black node has an out-degree of 6.

Let us denote the generic binary networking relation by the symbol "$\circ$". Now a set of any given three nodes N_i, N_j and N_k in a directed network is said to be a *transitive triplet* if $N_i \circ N_j \circ N_k$ and $N_i \circ N_k$ where i, j and k are distinct. A triplet is called a *cycle* if $N_i \circ N_j \circ N_k \circ N_i$ holds. A small world network has much more transitive triplets and cycles than the equivalent random network. The equivalent random network can be constructed to have the same number of nodes and the same out-degree distribution as the original network. A summary of comparison between simulated networks and equivalent random graphs can be seen in Figure 7.

			Social Network		Council Network	
RUN	Resource	Population	TT-Ratio	C-Ratio	TT-Ratio	C-Ratio
1	5000	1031.6	4.03	1.77	5.23	1
2	10000	2051.2	5.52	2.27	6.43	0.93
3	15000	3225	5.46	1.85	7.39	1.01

Figure 7. Properties of social and council networks in comparison to random graphs of equivalent degree distributions

Three runs of the simulation with different resource levels are used in this comparison. The networks in each run are sampled at five different times selected after the simulations are out of the initial transient phase. For each sample, three equivalent random graphs are generated. TT-Ratio denotes the ratio of the number of transitive triplets in the simulation to the average number of transitive triplets in generated random graphs, averaged over five samples. This ratio signifies the degree of transitivity of the network forming relation. Similarly, C-Ratio denotes the ratio of cycles calculated as such and correlates with the degree of symmetry of the network forming relation.

Complete data used for this analysis can be found in Appendix D, Figures D1, D2 and D3. As seen in figure 7, networks of both relations exhibit clustering. Social network of acquaintances has roughly 5 times as many transitive triplets and double the number of cycles, implying a heavy clustering coefficient reminiscent of who-knows-whom relations observed in social networks. Council network is even more transitive but practically equivalent to a random graph in terms of cycles. The case with the council network is particularly informative because it reflects on the operating trust model we use to form councils. Since the council network is more transitive than the social network while being its subset, we can conclude that our trust model demonstrates transitivity as an emergent property. This is a property of the network relation and signifies the prevalence of the transitive instances of the underlying binary relation. Furthermore, the council network has half the ratio of cycles as its parent set and this reflects the notion that council relation in a single context is inherently anti-symmetrical since the cycles provide a way to extend the concept of symmetry over longer relational chains. With a single context trust relation, if i takes advice from j and j takes advice from k, it is counterintuitive for k to take advice from i.

5.2 Observations

The world and the society inhabiting it are considered as interacting systems. So it's natural that the model exhibits some properties related to the resource characteristics of the chosen world.

5.2.1 Population dynamics

A starting population called ancestors is initially created, after this point, individuals are born. Any population in the model is said to be sustainable if the individuals are able to survive and accumulate enough wealth to mate and produce at least two children. When this condition is fulfilled, resource regeneration rate of the world (ρ) is seen to be the most important determinant of the equilibrium population of the sustained society. This is the population that uses all new available resources allowing a stable resource level. Resource capacity or initial resources change the manner of convergence to this equilibrium. If a higher resource capacity is set with the same settings, this does not alter the equilibrium levels but it takes longer for the system to reach this equilibrium as demonstrated in Figure 8.

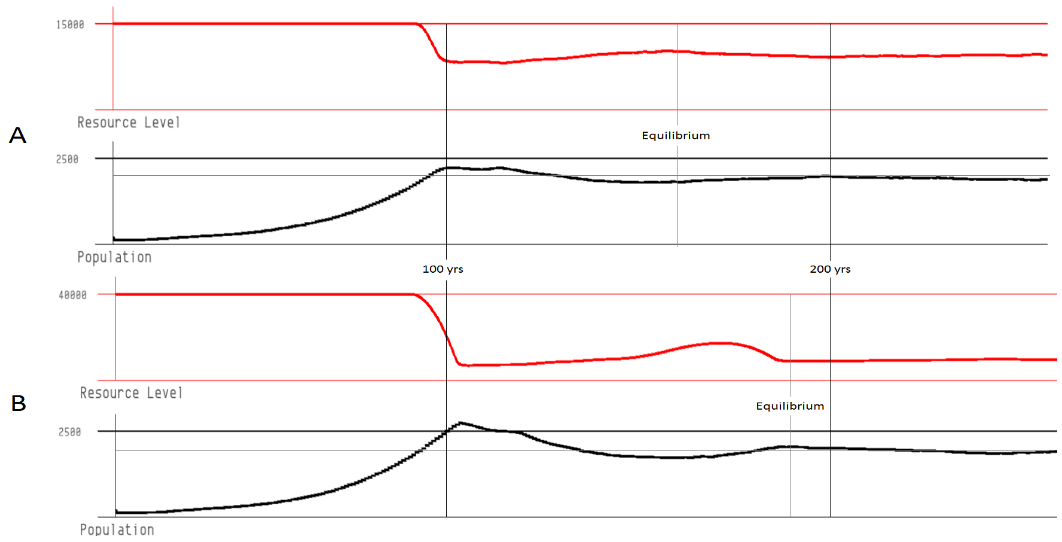

Figure 8. Effect of resources on convergence to equilibrium, (A) has modest resources in the beginning and (B) has excess resources causing a slower convergence to equilibrium population

There is an exception to be mentioned here. If the resource capacity is astronomical and resource regeneration is very low, a drastic overpopulation may occur. Resources are completely drained and the population dies. The reason for this unintuitive outcome is that by design, all individual actions are synchronized in the model. This means that all individuals have access to what little resources the world provides, causing the entire population to starve simultaneously. In a real life scenario with so little resources, people who act first to tap the remainder of resources would survive at the expense of others, allowing them to repopulate the society towards the equilibrium level. In this case, our underlying assumption of a benign society clearly breaks. Our model can not realistically simulate an extinction-level resource crisis.

5.2.2 Dissemination of wealth

In the model, all wealth in the society comes from the resources of the world. So we can consider that the system combining the world and the individuals, has a definite wealth in resources/benefit. This wealth of the system accumulates by the resource regeneration and it is drained by the living costs of individuals that inhabit the world. In the equilibrium population, almost all wealth in the system is in the form of society's wealth. In other words, resource input to the system (ρ) not only defines the equilibrium population but also defines the carrying capacity of wealth in the system which consists of the raw resources in the environment, biological energy of the population and its material capital. Time evolution of the total accumulated wealth in the system can be seen in Figure 9.

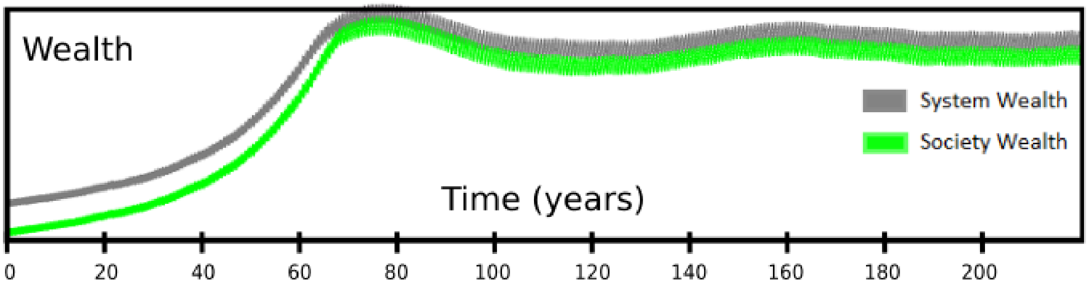

Figure 9. Accumulation of wealth in the system. Gray line represents total wealth in the system as a function of time. Green line represents the wealth accumulated by the population.

Individuals in the population do not possess equal shares of this wealth. In fact, age is seen to be the primary determinant of an individual's wealth. Distribution of wealth among the individuals in equilibrium population can be seen in Figure 10.

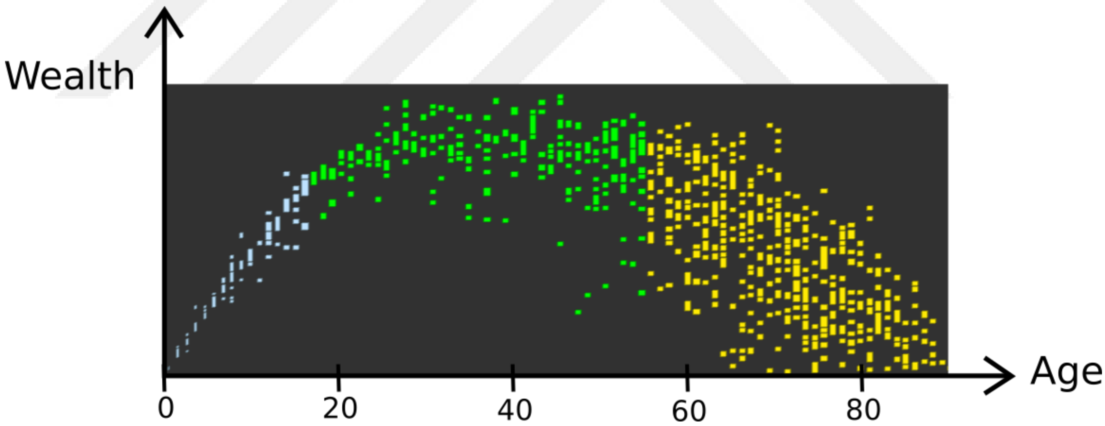

Figure 10. Scatter chart of individuals' ages versus their wealth. White, green and yellow dots represent children, adults and elderly

It is important to note that the wealth of an individual also represents the well being or physical fitness in addition to the material wealth accumulated by the individual. Most of the wealth of the younger population is in the form of well being and most of the wealth of elderly is in the form of material wealth. Lower variance in the wealth of younger individuals can be misleading, children of wealthy parents tend to eventually inherit a larger material wealth but this wealth is in the possession of their parents when they are still young.

5.3 Analysis of trust

Many formulations of trust involve a particular type of action that justifies the phrase of *acting on* said trust (to trust a person X to do action Y). Without this accompanying action, it may be superfluous to talk about any kind of trust. Primary action in our model to warrant trust is the act of giving advice. Thus the council of an individual is exactly the set of others that the individual trusts. A truster i having complete or maximal trust in an individual j at time t in the model entails that

(i) the individual j has provided flawless estimations to the outcomes of truster's actions so individual i has high trust in individual j ($\tau_{ij} = 1$) and

(ii) the individual j is also currently an advisor in the truster's council meaning that individual i acts on its trust for individual j. ($j \in \mathbb{C}_i(t)$).

We will introduce the following methodology to analyze how trusting depends on age. The individuals are grouped into *age groups* (G^*_j) of k years such that for an individual i, $i \in G^*_j$ if and only if the age of i, $t_i \in (kj, k(j+1)]$ for all $j \in \mathbb{N}$. The oldest individual's age group is the non-empty group with the largest index. Let's call this index g. We build a $g \times g$ matrix called the *council trust matrix* (T) to represent trust relations between the age groups. In order to correct for the age demographical state of the population, the following method is used. Each cell of the trust matrix T_{ab} represents the trust between two groups G^*_a and G^*_b of sizes

$\|G_a^*\|$ and $\|G_b^*\|$ respectively. if $a \neq b$, T_{ab} is normalized by $\|G_a^*\| \cdot \|G_b^*\|$ such that $T_{ab} = 1$ when all members of G_a^* have complete trust in all members of G_b^*. When $a = b$, this is impossible since maximum possible trust is achieved when all members of G_a^* have complete trust in all members of the same group except themselves. In this case, T_{aa} is normalized by $\|G_a^*\| \cdot (\|G_a^*\| - 1)$ such that when the maximum possible trust obtains, T_{aa} becomes 1. $T_{ab} \in [0, 1]$ for all a and b.

Typically the size of councils is much smaller than the sizes of age groups. This means that even in the case where all councils of the members of a group consist of members of a particular group, the trust between these groups can only be as large as the ratio of the council size to the size of the smallest group.

It is also seen from this formalism that losing trust is easier than gaining it because the trusted individuals are frequently consulted by the truster but untrusted individuals who are not in the council must be encountered stochastically so that they can provide good estimates to improve their trustedness. An individual's trust incorporates trusted others into the social practice of this individual and his/her distrust excludes them from it. In short, once the trust is lost, it becomes harder to gain it back.

5.3.1 Age dependence of trustedness

Now we can define a metric for the trustedness of an age group by summation over the columns of the trust matrix T. Trustedness of all age groups at time t can be denoted by a discrete probability distribution, Trustedness(t). Trustedness of babies is generally the lowest and trustedness seems to be positively correlated with age. However the characteristics of this correlation change depending on the state of the simulation world. Trustedness of age groups can be seen as a distribution over the age spectrum. Like any distribution function it can be approximated by its first three central moments: the mean, variance and skew. Because this distribution is possibly multi-modal as observed during the simulations, the mean of the distribution can be misleading to characterize the distribution. Variance of the distribution in the simulation is seen to be quite chaotic around a fairly constant mean variation and it does not indicate anything significant. On the other hand, we found the skew, or third moment (M_3) to be a meaningful quantity to our analysis of age dependence of trust. If the skew of the trustedness distribution is negative, it can be said that the trustedness is positively correlated with age. If the skew is positive, trustedness is negatively correlated with age instead. A graph of M_3 as a function of time during a simulation with an off-shooting population that converges to the equilibrium can be seen in Figure 11.

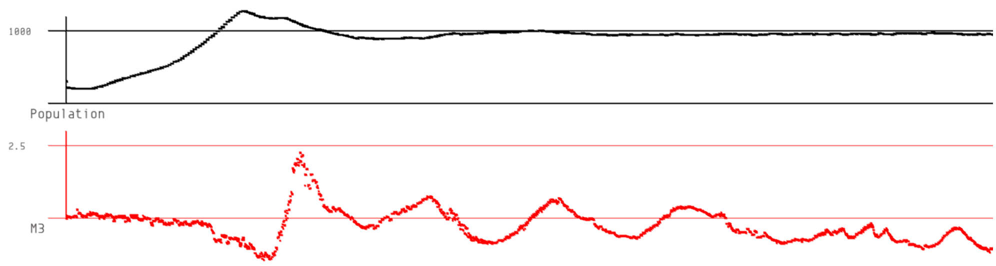

Figure 11. A 400-year run with population converging to equilibrium. Black line denotes the population and red line denotes the third moment of trustedness distribution.

We can see that M_3 quickly changes sign to positive after the effects of a resource crisis. During this event individuals start to take advice from younger individuals. After multiple fluctuations around zero level, M_3 stabilizes at a negative level after the population stabilizes around the equilibrium population meaning that older individuals are now deemed more reliable by others. In a relatively stable world, it is wiser to heed older individuals' advices.

5.3.2 Learning and competence

Children learn about the world via their actions which are initially guided by their parents. Each feedback to a performed action is used to update the feedback receiver's benefit estimate of the corresponding action. Since children's well being usually improve fast due to the scaffolding provided by their parents, they also tend to act with high exploratory tendency. This allows them to also learn about the outcomes of unwise decisions. As trust in an individual is the assessment of that individual's ability to provide accurate predictions which corresponds to their reliability as an outcome estimator, we could define reliability as having an accurate world model. However the quantitative accuracy of a world model, does not capture the notion of individuals learning to act better. So we will introduce a different criterion.

In our simulation world, we can define *competence* as the capability to choose correctly between alternative actions. This entails that the most competent individual has a world model whose order of preference for actions mimics the unique objective order of benefit outcomes for these actions. Any individual who would choose the best action to perform without any social guidance can be considered competent. We can generalize this notion to build a ranking based metric for competence. Details of this metric can be found in Appendix C. Note that this type of rank competence does not imply that the individual's world model quantitatively fits the objective world model. We can also define competence of an age group as the average competence of all members of the group. A few samples of the average competence of age groups versus their trustedness around the equilibrium populations can be seen in Figure 12.

This experiment is done with three worlds that have 10, 20 and 50 actions respectively. From Figure 12, it is clear that competence is quite correlated with trustedness. Furthermore, at all moments of the simulations, there seems to hold one of the three qualitatively distinct types of correlation patterns. We will tentatively call these states A, B and C. Type A is the most common occurrence, it is characterized by life long increases in both competence and trustedness. As the world gets more complicated, meaning it has more actions to learn, acquiring competence takes longer and trustedness does not increase as much with age. Type B is characterized by a decline in the trustedness of the older individuals. Type C is characterized by decline in the trustedness of the middle-aged individuals and higher trust in the old. These types of correlations are interpreted in more depth in section 5.3.4.

5.3.3 Inheritance of knowledge

Children in the model inherit their parents' knowledge of the world in the following way: Initially parents' world models are imprinted upon the children rendering them as inexperienced blends of their parents. Children's world models are then updated as the result of their actions which are mostly guided by their parents. This scaffolding relationship allows all parties to gain competence. As competent parents promote the best actions, the child learns of these actions and gains competence. The child also explores the bad actions and comes to trust their

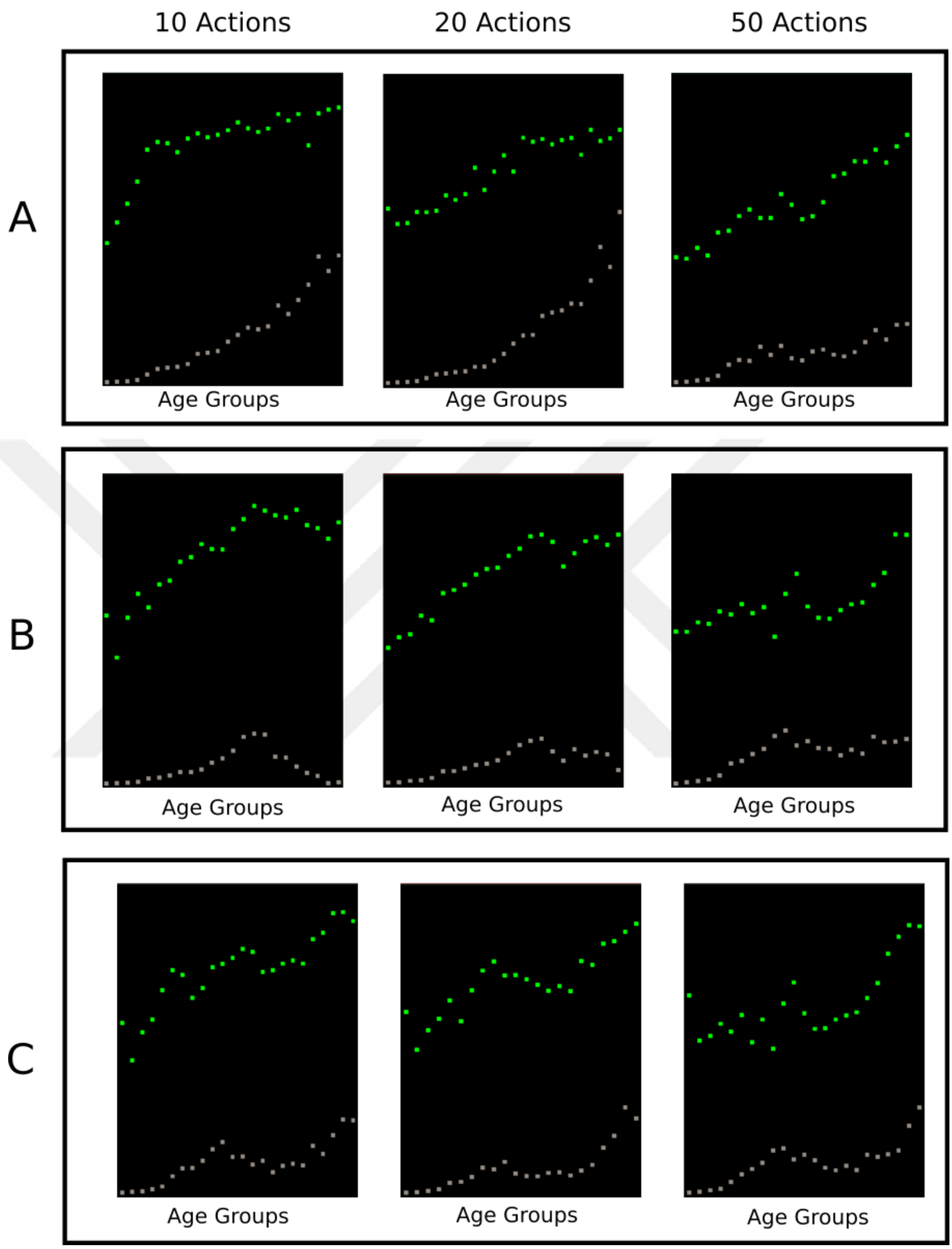

Figure 12. Classification of competence-trustedness correlation types in simulation worlds with increasing difficulty (increasing number of actions). Green dots represent average competence of age groups and gray dots represent their trustedness (or reliability as perceived by the people who trust them)

parents as a result because their knowledge of these actions tend to be better than the child's knowledge. In return, parents get updated information about the outcome of bad actions allowing them to be even more reliable. It can be said that parenting allows inheritance of the knowledge by (1) bestowing knowledge of the optimal actions on children via the process of advising and (2) providing safety to children, allowing them to experiment with suboptimal actions.

5.3.4 Demography and trust

The relation between competence and trustedness is more complex than a correlation. Trustedness of an individual results from other individuals' trusting. After an advice, the truster needs to rely on the single information available to reassess the reliability of the adviser: the output of the performed action. In contrast, the competence of the adviser can never be assessed by other individuals. As the individuals get older, their world models become more anachronistic: Experiences of some actions are more up-to-date than those of other actions. We will call these actions *current* and *dated* for the individual respectively. Performers of actions that are current for the elderly grow trust for them and performers of actions that are dated for the elderly lose their trust. Being trusted less amounts to getting consulted less, and this results in losing touch with what other individuals are doing. In other words, trustedness improves reliability.

Paradoxically, the adviser improves his reliability the most when his advice is deemed by a truster to be the worst. Adviser loses trustedness since he has provided a bad estimate but becomes more reliable because the feedback he receives makes the performed action current for him. Since interpersonal trust has a certain inertia gained by prolonged interaction between individuals, a few bad advices usually do not jeopardize it by much. But by this exact reason, the trust of the young is more easily won and lost.

Positive correlation of trustedness with age is not simply a result of the relative competence and reliability of older individuals, but it is naturally defined to be this way. Initial councils consisting of parents are some 20 years older than a baby so in a sense, all councils favor older individuals. Also, since the network formation mechanics simulates community exploration, the children initially explore their parents' networks which only amplifies this effect. States A, B and C from Figure 12 are direct results of demographical changes. State A is observed under normal conditions accompanied by a stable population demographics while the states B and C are transitional states. State B is observed some 60 years after a quick population boom accompanied by better conditions, typically resulting in a larger population of older adults whose world models reflect the 'good old times'. State C is observed some 40 years after a crisis when younger individuals' world models are comparable to their grandparents' generation but not to their parents'.

Parents of the crisis era exhibit a special sort of declined competence due to a lack of leisurely exploration of the action domain. They are initially good parents while raising their children, but when their children start experimenting with suboptimal actions, their unreliability as councils becomes apparent.

5.4 Individual strategies for decision

An individual's actions reflect on the varying decision strategies employed by that individual conforming to dynamics of its confidence vector $\underline{C_i}(t)$. When confined to the isolated scope of the individual, confidence mechanism may seem trivial. However, the confidence dynamics of a society is considerably complex and expressive because each individual's confidence indirectly modulates the dissemination of world information in the society network by locally changing the feedback relations between the world and the individual's affine social network. Confidence of the individual is in turn affected by this modulation.

First, let us note that since confidence vectors can be made normal, that is $\|\underline{C_i}(t)\| = 1$, we can represent them in simplex coordinates along the simplex (S_3). Now we can represent the decision strategy state of a society as a scatter chart in this simplex. Figure 13 shows an example of such a state.

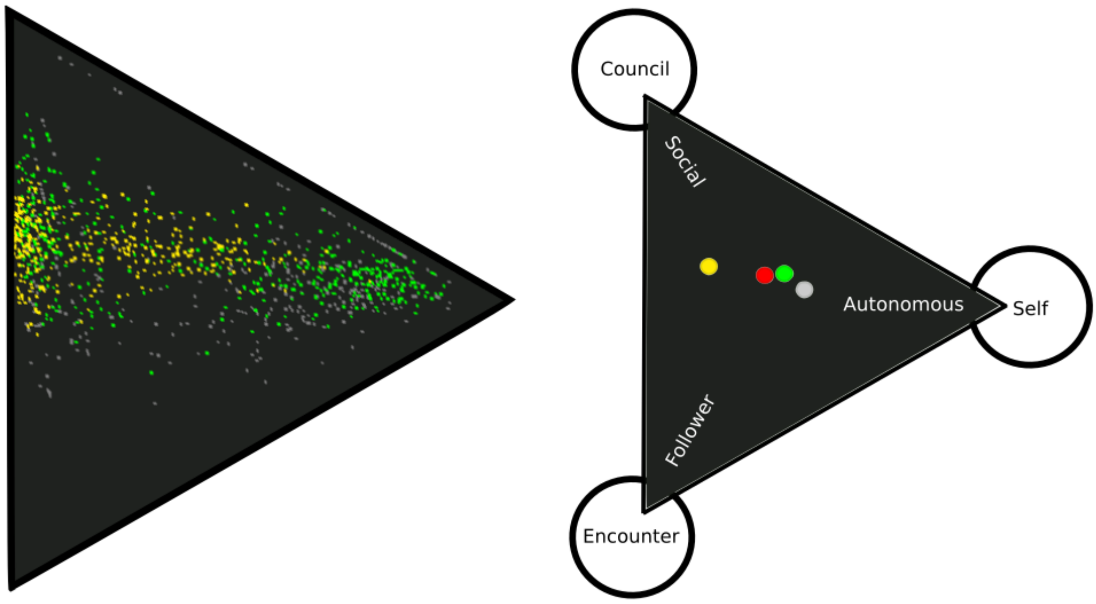

Figure 13. Scatter chart of decision strategies by individuals in the society

In Figure 13, gray dots denote children, green dots denote adults and yellow dots denote older individuals in the left figure. Average tendencies of these groups accompanied by the red society average are shown on the right with their respective colors. Defining strategies associated with the regions of the simplex are also shown in the right figure.

Average decision tendencies of children, adults and elderly is an indicator of the general development of these strategies as the individuals age. Children and young tend to be more autonomous and spontaneous because their councils as well as their personal networks are limited, they also tend to be over confident. In contrast, older individuals heavily rely on social and consensual strategies which are generally slower to build up. Yet, these average tendencies and the generalizations they elicit, can be misleading because there is a significant amount of variation in each of these very broad groups. In the next chapter, we will use a different approach in order to understand the societal impact of confidence dynamics.

5.5 Properties of action domains

In section 4.1, we had defined three qualitatively distinct types of action domains characterized by the type of frequency dependency they exhibit: neutral domains ($f = 0$), positive frequency dependency (PFD) domains ($f > 0$) and negative frequency dependency (NFD) domains ($f < 0$). These abstract categories are ideal in the sense that none of them perfectly coincides with common worldly situations or contexts. Yet they are useful as virtual building blocks to characterize the types of situations that occur in the real world.

(i) In neutral or frequency-independent domains, actions are not affected by others' actions. This is typically the case with the situations where the actions only involve the actor i.e. there is no social interaction involving this action. A pure neutral domain resembles a domain consisting of interactions with an immutable external entity in static social settings.

(ii) In PFD domains, popular actions become favorable because their actual benefits increase with the frequency of usage. This is characteristic of the types of situations where a cooperative dynamic interaction is involved. Whatever the dynamics of this interaction is, individuals benefit from matching what the others are doing since the coordination of actions which really denote meta-actions in this thesis, may correspond to any establishment of a division of labor observed in cooperations. A pure domain of PFD with sufficiently strong frequency dependency eventually turns into a special type of domain where one action is the norm and deviation from this norm is very costly. If the frequency dependency is relatively weak, this results in an interplay of competing conventions.

(iii) In NFD Domains, uncommon actions become favorable. This is characterized by situations where actions are part of a competitive dynamics of interactions. Nature of these interactions may vary but the individuals benefit by counteracting other individuals' actions. A pure NFD domain with strong frequency dependency resembles a domain of fierce competition for resources, in the long run it turns into a bustling playground of momentary opportunities. If the frequency dependency is weak, it operates like a regulatory network that promotes diversity.

We calculate the Frequencies of Actions such that recent actions contribute exponentially more to the frequencies of these actions than older actions. In other words, we use an exponential forgetting of older actions. Frequency of an action a

at time t is calculated as follows:

$$\phi_a(t) = \alpha_\phi \cdot \phi_a(t-1) + \text{Performance}_a(t) \tag{5.1}$$

where $\alpha_\phi \in (0, 1)$ denotes the *salience weight* and indirectly defines the time frame of frequency dependency. The choice of this time frame is of great importance for our model. In a competition for a table in a popular restaurant, only the recent flood of customers is relevant, while the competition among entrepreneurs happens over a longer period. Same logic applies to the positive frequency dependency domains. A smaller α_ϕ is typical of sporadic conditions and larger α_ϕ entails slow building and resilient conditions. We chose α_ϕ such that the effect of a most recent action is three times larger than the effect of an action performed one year ago. Our considerations while adjusting α_ϕ can be found in Appendix A.

To summarize, the frequency dependency of an action domain loosely expresses the qualitative nature of the social interaction dynamics underlying the actions that are available for the individuals to perform. As the frequency dependency increases, so does the synergy between the individuals who are coordinating on the same action. The relation between these abstract domains and nature of interaction dynamics is informally depicted in Figure 14.

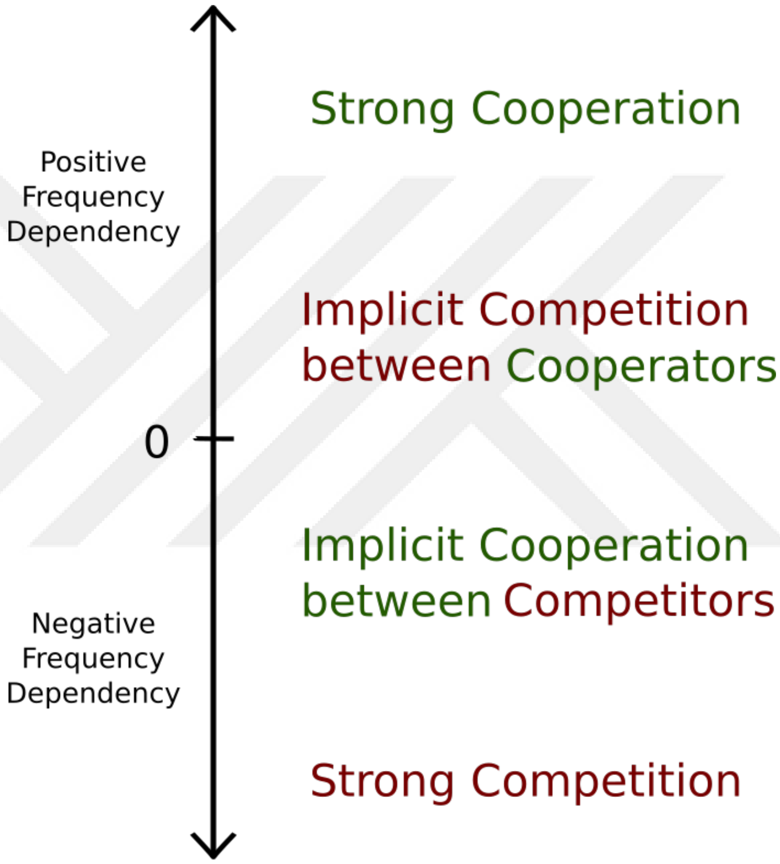

Figure 14. The various natures of social interaction dynamics underlying frequency dependent domains of actions

CHAPTER 6

META-ANALYSIS OF GENERATIONAL FINDINGS

We have seen that for a reasonably wide range of parameter values, the model allows for a sustained, multi-generational population dynamically adapting to the conditions co-evolving with it. We call it multi-generational because at each moment it contains babies, their parents, grandparents and so on. In fact, each individual is the descendant of a certain subset of the initial created population we called ancestors.

The word *generation* is known to be used to denote a number of different things. Most common usage expresses familial generations where children and their parents are understood to be two consecutive generations. It is also common to use the word generation to broadly refer to larger group of contemporaries typically belonging to some identified era. However, it is not easy to define a generation in a non-arbitrary manner. On the one hand, it is unreasonable to definitively characterize a typical range of ages for a cohort of individuals likely to be identified as a generation. Any ad hoc choice of range prior to an in-depth investigation will be arbitrary. Secondly, individuals in any age group are diverse in their choices, norms and states of mind. Therefore a definition of generation may not strictly require the members of that generation to exhibit the typical characteristics. With these considerations in mind, we refrain from such an explicit definition of a generation at this moment and concentrate on the mechanisms involved in the formation of generational differences themselves.

In order to do this, we introduce a formalism for comparing two presumed groups of individuals $\mathbb{G}_1$ and $\mathbb{G}_2$ graphically depicted in Figure 15.

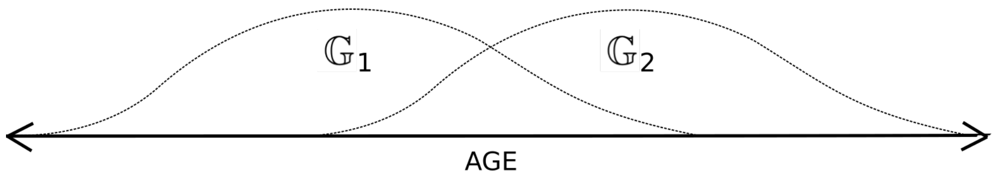

Figure 15. Graphical representation of two groups of individuals with overlapping age distributions

Each of these groups in Figure 15 is composed of individuals whose ages are assumed to have a distribution around a central mean age. Groups $\mathbb{G}_1$ and $\mathbb{G}_2$ have distinctly separate mean ages and possibly overlapping age distributions. They are of arbitrary sizes which may not correspond to familial generations. For analysis purposes, these groups (or proto-generations) will function as molds for emerging generations distinguishable with respect to some arbitrary property.

6.1 Strategy signatures in equilibria

We can chart the individuals' average reliances on themselves, their councils and arbitrary encounters as a function of their ages. These average reliances correspond to the prevalence of autonomous, social and follower strategies among individuals as a function of their ages. This chart from now on will be denoted as the *strategy state* of the society at a given time. Figure 16 shows the typical strategy state in the equilibrium state of the population. In the equilibrium conditions, strategy state resembles a standing wave exhibiting fairly constant qualitative characteristics save for some mild quantitative changes and noise. We will call this equilibrium strategy state, the *strategy signature* of the world because its qualitative features depend on the specific action domain and nominal benefit distribution that make up the world. Figure 16 is the strategy signature of the neutral action domain.

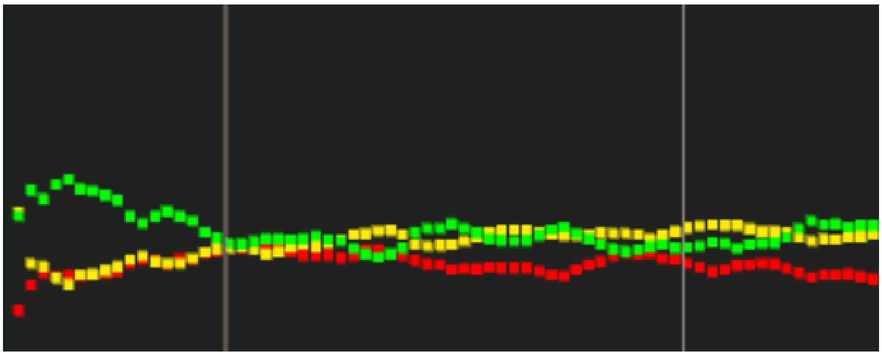

Figure 16. Strategy signature of the neutral action domain, x-axis represents ages and y-axis represents the prevalence of decision strategies

A higher relative prevalence of a strategy around an age in the strategy state implies a systematic tendency of the individuals around that age to favor that strategy. In Figure 16 and in all strategy state charts, green denotes the autonomous strategy, yellow denotes the social strategy and red denotes the follower strategy. In this specific domain, we can see that children tend to display more autonomy, the effect of social strategies shows slow and monotonous increase and that of following tendency decreases after ages 30s.

6.2 Changes of external origin

In order to investigate how exogenous changes impact the simulated society, some parameters of the simulation can be changed during run-time. Figure 17 lists the appropriate parameter changes corresponding to some examples of possible real life events which can induce analogous changes. We will refer to any change of external origin attained by run-time changes made to the fundamental parameters of the model, as an *external impact*. We will be using only resource related changes in this chapter as proof of concept, leaving a more detailed canvas of the other types of external impacts for future studies.

Real Life Events	Change in Parameters
Abundance of Resources	Increase in Resource Regeneration (ρ)
Resource Crisis	Decrease in Resource Regeneration (ρ)
Plagues and Wars	Increase in Stochastic Mortality (μ)
Welfare Improvements	Decrease in Stochastic Mortality (μ)
Advances in Communication	Decrease in Social Conservatism (P_{con})
Vaccination Campaigns	Increase in Baby Immunity (L_0)
Changes in Matrimonial Norms	Changes in Reproduction Interval (A_{rep})
Technological Advances	Changes in Nominal Benefits (B)
Change of Economic Systems	Changes in Wealth Inheritance

Figure 17. Some examples of external impacts and corresponding parameter changes

External impacts can cause systematic changes in the behaviour of individuals. The nature of these changes depend greatly on the details of the particular external impact and momentary ambient conditions. But in any case, such changes manifest most apparently as a perturbation in the strategy signature. Before the impact, strategy state is in equilibrium and can be qualitatively described as a strategy signature. In the long run after the impact, strategy state again attains an equilibrium state and represents a strategy signature. However in the short run, strategy state is in a transient phase in which it can not be summarized as a strategy signature. Figure 18 shows the strategy states of a society operating on a neutral action domain in the immediate aftermath of a dramatic rise in resource input to the system, expressing a new found abundance.

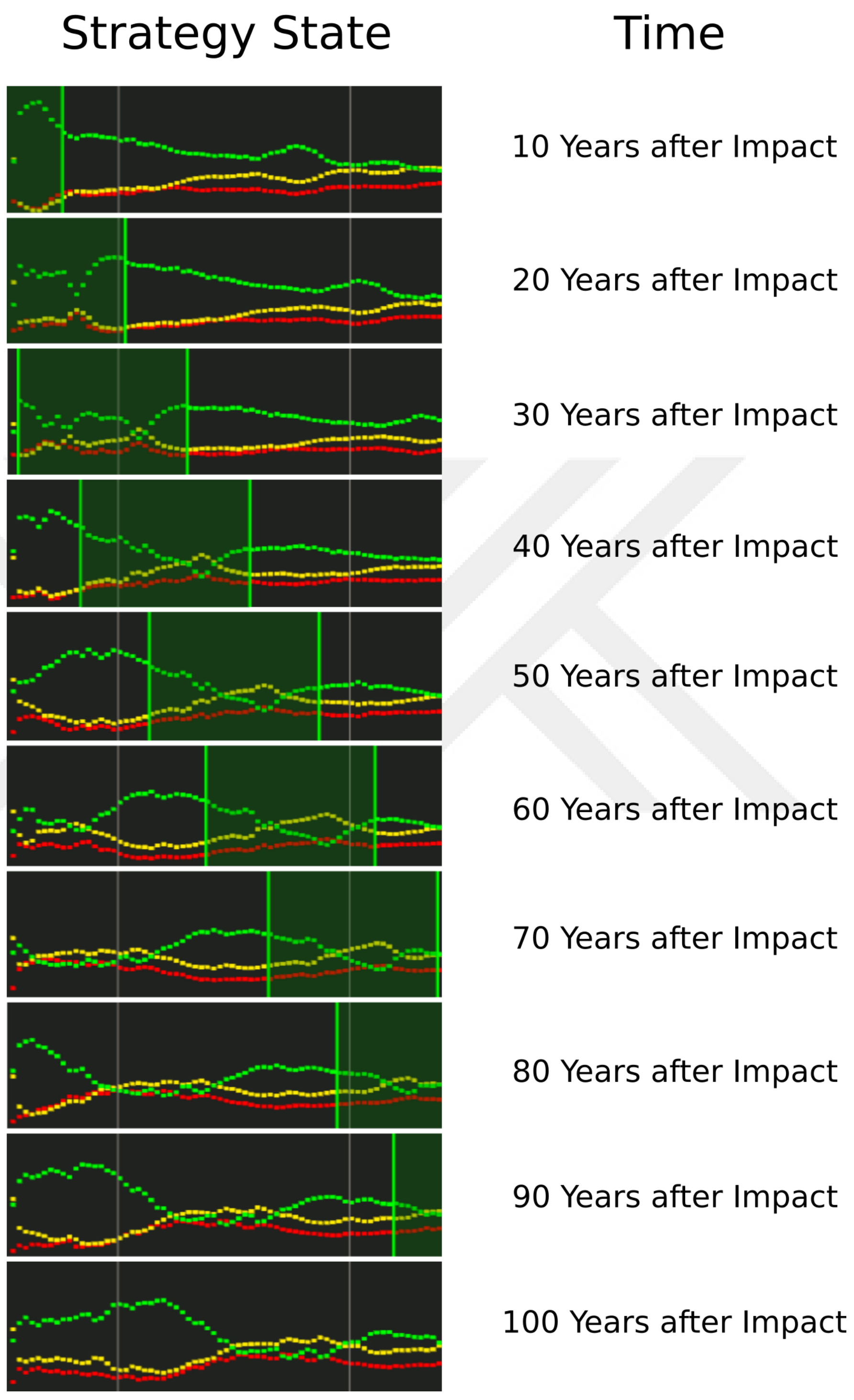

Figure 18. Strategy states of the neutral action domain during the transient phase in the aftermath of a rise in resource input to the system

Shaded areas of the strategy states in Figure 18 indicate the present range of ages of those who were born during the immediate repercussions of the external impact. As can be observed from figure 18, in the transient phase, time evolution of the strategy state exhibits a pattern of relative tendencies of different strategies in range of ages resembling alternating blocks, consisting of blocks of autonomous tendency followed by blocks of social decision tendency. The confidence block generated by the external impact can be seen in Figure 18 shifting towards older ages. These blocks represent clusters of individuals of like ages who tend to employ a specific decision strategy and the pattern composed of these blocks travel towards the older ages as the involved individuals get older. Furthermore, these patterns are observed to reproduce themselves in subsequent age ranges. It is important to note that depending on the nature and the strength of the external impact, this transient phase can perpetuate for centuries beyond the lifetime of individuals who experience the event. The differentiation of individuals in strategy preferences does not by itself imply that they will act differently. Yet, we will see that this type of systematic divergence has the potential to turn into a divergence of norms and behaviour in the society.

For each single individual, autonomous, social and follower strategies are in an intrinsic competition modeled by the confidence dynamics of the individual. Prevalence of follower strategy in the society is not significantly affected by an external impact, but autonomous and social strategies are also in dynamic competition in the society. This competition which lies dormant under equilibrium conditions is evoked by the external impact because specific strategies are differentially affected by it. After an external impact, estimation accuracy of all strategies initially diminishes until the world models of individuals adapt to the new conditions. However, the reliability of individuals' councils similarly depreciates and this may result in a change in the composition of these most trusted sets of acquaintances. As the councils are not fixed during the period when the world conditions change, social strategy adapts to the world more slowly than the autonomous strategy. There is a certain internal logic to the repetitive nature of the blocks observed during the transient phase of the strategy state dynamics.

6.3 Generational differences in strategies

We will now describe the interaction between autonomous and social strategies in the society observed during the transient phase of the strategy state dynamics. The beginning of the process of divergence of this type is characterized by an asymmetric limitation of communication between some groups $\mathbb{G}_1$ and $\mathbb{G}_2$. This entails particularly low trust (in any direction) between these groups causing one of them to act more autonomously. Such a tendency is usually triggered by a rapid change in the world either resulting from external impacts or in a self organized manner. Sizes of these groups ($\mathbb{G}_1$ and $\mathbb{G}_2$) depend very much on how long it takes for the society to adjust to the external impact. Yet as stated before, once two groups diverge in decision strategies, the resulting pattern has the property of reproducing itself.

First we note that individuals' councils are predominantly older than themselves due to the nature of the network formation mechanism used by the individuals to acquire their acquaintances. Secondly, we observe that reliability and competence of individuals are affected differently by an external impact resulting of their decorrelation in the society. When a divergent strategy block emerges around an age, one of the two possible scenarios graphically described in Figure 19 follows. Each of these scenarios starts a cascade of interactions which reiterate both scenarios in sequence until the pattern dies off due to stochastic factors. We will denote these scenarios (a) and (b) to describe them in detail.

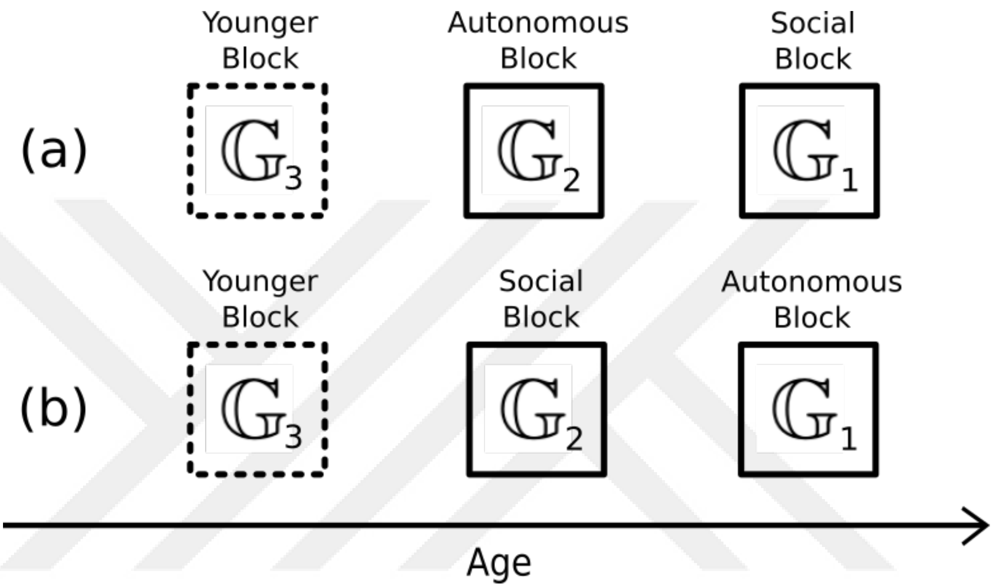

Figure 19. The interactions between consecutive blocks of strategies in the two scenarios explained as (a) and (b)

(a) A block $\mathbb{G}_2$ of more autonomously acting individuals of close ages, provide less feedback to their networks i.e. do not report their experiences to their council members because they did not heed their advices. Their older council members are temporarily left behind in reliability causing the socially inclined members of $\mathbb{G}_2$ to replace them with their peers and younger acquaintances. This causes the consecutive older block $\mathbb{G}_1$ to get structurally isolated in the society network. As this reversal in trust relations of the social individuals in $\mathbb{G}_2$ also improves the younger members of $\mathbb{G}_2$ in competence and reliability, they become more autonomous in time, differentiating from their parent generations. Since the older tail of $\mathbb{G}_2$ contains these parents, they will lack in reliability in their old ages, switching to social strategies. The block shrinks from the right and $\mathbb{G}_1$ grows. On the other hand, younger tail of $\mathbb{G}_2$ are excellent councils and this reflects on the block of incoming younger individuals, $\mathbb{G}_3$ that follows, they grow to be social decision makers. This results in the condition which triggers scenario (b).

(b) A block $\mathbb{G}_2$ of individuals of like ages who take more socially instigated decisions provide ample feedback to their networks who are in the older tail of $\mathbb{G}_2$ and in $\mathbb{G}_1$, these council members adapt better to the changes in the world, slowly becoming more autonomous and providing less feedback to the block in their old ages. Hence $\mathbb{G}_1$ grows. Individuals in $\mathbb{G}_2$ rely on their councils and quickly navigate to the optimal actions before the rest of the society so they are trusted by the competent younger individuals of $\mathbb{G}_2$ who in turn grow into social decision takers. Individuals in the younger tail of $\mathbb{G}_2$ are very competent and good role models but ultimately unreliable councils since their experience is heavily concentrated in optimal actions. As a result, when the incoming block of younger individuals in $\mathbb{G}_3$ start experimenting with suboptimal actions, their councils in $\mathbb{G}_2$ prove ineffective as estimators of action consequences. Thus individuals in $\mathbb{G}_3$ grow to be more and more independent and autonomous actors, isolating $\mathbb{G}_2$ from younger generations. This results in the condition which triggers scenario (a).

In both instances, downwards propagation of wisdom from the old and the upwards propagation of discovery from the young are disrupted in the society. Depending on world conditions and demography, the society can become prone to divergence of norms and behaviour. The generational differences only become explicit when behavioural differences between subsequent strategy blocks emerge. This is the stage where we can observe and remark on the existence of distinguishable generations $\mathbb{G}_1$ and $\mathbb{G}_2$. In order to explain how a differentiation of decision tendencies translates into a differentiation of actions, we must concentrate on the features of different types of worlds and social interaction dynamics which may determine the consequences of individuals' actions.

6.4 Analyses of different worlds

We described different action domains in the previous chapter. In a sense, these action domains define the social nature of the individuals' actions. In the neutral domain where the nature of actions is distinctly asocial, any happenstance of behavioural differences do not interact with the strategy state of the society. On the other hand, frequency dependent domains exhibit something very different. We treat these types of pure action domains as abstract archetypes for worlds which are characterized by cooperative and competitive interactions. Thus we discuss PDF and NDF domains under the titles of *cooperation* and *competition* domains colloquially. It is assumed that as the frequency dependency increases so does the synergy of the actions performed by the individuals who coordinate on the same meta-action.

In cooperation domains, meta-action alternative X can be understood as 'Collaborate with others in order to do X'. Under this formalism, the types of collaborations with a demarcation of the participants' roles in order to achieve a specific goal X can be considered as stemming from an initial coordination of the meta-action X regardless of the particular characteristics of the cooperation which involves the participants. Similarly in competition Domains, meta-action alternative X can be understood as 'Compete with others for the opportunity X'. So the expected gain of each competitor is adversely affected by the number of competitors for this opportunity. Only further assumption we have to make is that all collaborators contribute and benefit equally and that all competitors fare equally well. Yet as indicated in section 5.5, these pure action domains may not strictly characterize the type of implicit interaction dynamics underlying the actions, thus the terms cooperation and competition should best be interpreted as special terminology in this thesis.

6.4.1 Cooperation domains

We define cooperation domains as the action domains with positive frequency dependency. The defining feature of these domains is that one of the actions of this domain becomes the social norm and performing this action becomes the optimal choice. In the case of weak cooperation, abiding by this social norm improves the well being of individuals marginally where in the case of strong cooperation, any choice of action except the social norm spells disaster for the individual. More often than not, nominally best action becomes the social norm, however it is possible for some other action other than the nominally best action to become the norm. If this is the case, the entire society can be considered in a Nash equilibrium, a stable state of the system involving the interaction of different participants in which no participant can gain by a unilateral change of strategy if the strategies of the others remain unchanged. Thus from this point on, the adopters of the nominally best action are penalized unless a large enough group adopts the action en masse. Figure 20 shows the typical strategy signatures of these domains. In both domains, autonomous strategy is common for the young and social Strategy is common for the old, but there are differences.

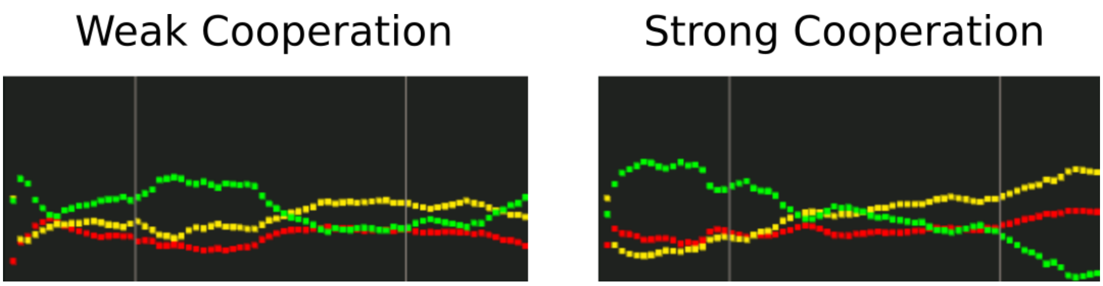

Figure 20. Strategy signatures of the weak ($f = .05$) and strong ($f = 1$) cooperative domains exhibit similarities and differences

Strongly cooperative world is much easier to learn as the penalty for the deviation from the social norm is absolute, so the children quickly become more self confident and independent. The council consisting of their parents is usually less reliable than the strangers they meet, as these strangers are usually older than their parents and unlike in other domains, they do not deteriorate in their ability to reliably estimate the consequences of suboptimal actions as they age. Also in the strong cooperation domain, individuals' councils become so reliable around midlife that they gradually turn to social strategy and eventually employ minimal autonomy in old age.

In Figure 21, we can see the nominal benefits, cumulative performance frequencies and actualized benefit returns of actions in some example domains of these types in the equilibrium state of the population. It can be seen that in weak cooperation domain, suboptimal actions are still performed to some extent while in the strong cooperation domain, optimal action becomes predominant.

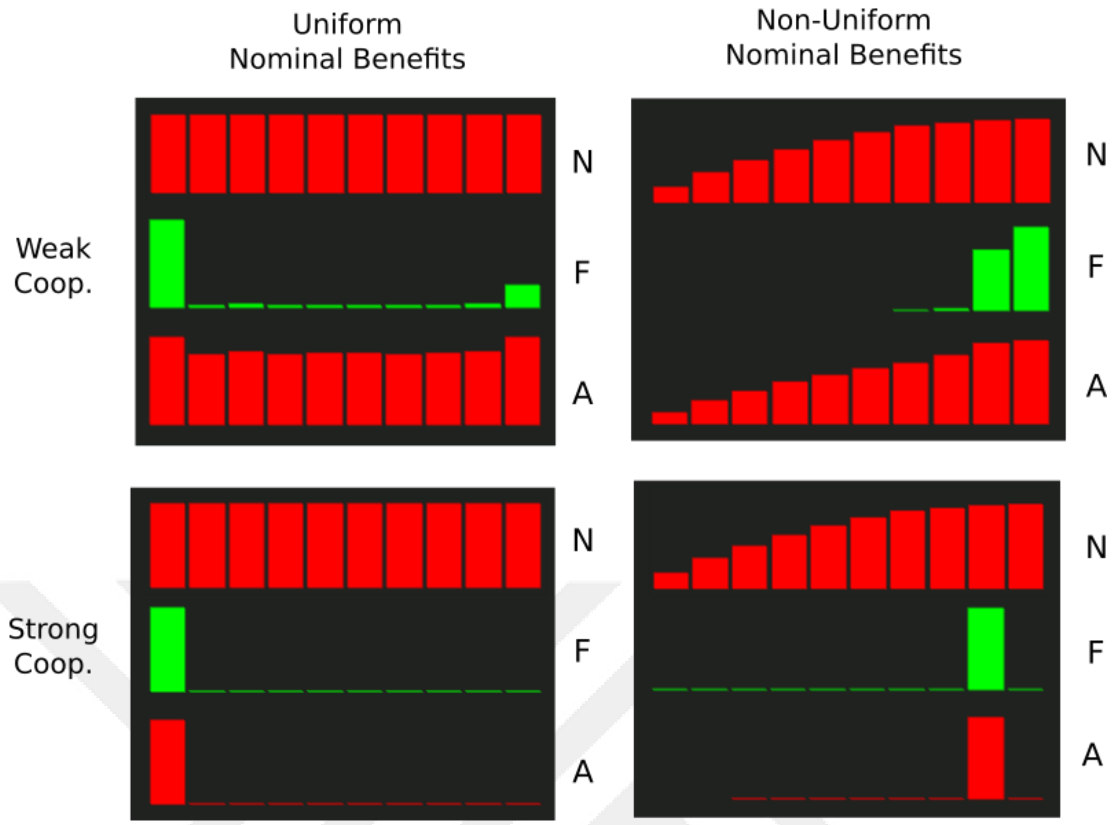

Figure 21. Benefit values and cumulative performance frequencies of actions in cooperative Domains. (N: nominal values, F: cumulative frequencies, A: actualized values)

In the case of uniform nominal benefit distribution, optimal action is randomly selected by the population corresponding to arbitrary social norms and conventions. In the non-uniform case, nominally best actions are more likely to be selected. Let us note that the non-uniform case with strong cooperation (bottom right) in the Figure 21 is from an example where a nominally suboptimal action has emerged as the monolithic social norm corresponding to a Nash equilibrium.

We will see that the societies in weak cooperation domains are less likely be stuck in Nash equilibria because they are more likely to switch social conventions during perturbations. Each switch between these social conventions increases the chances of the establishment of the nominally best action as the dominant convention. The changes in social norms and conventions occur due to the existence of the previously explained blocks of strategies in the strategy states of societies after an external impact. We review the effects of a sequence of external impacts pertaining to a resource abundance and then a resource crisis on the weak cooperation domain in Figure 22.

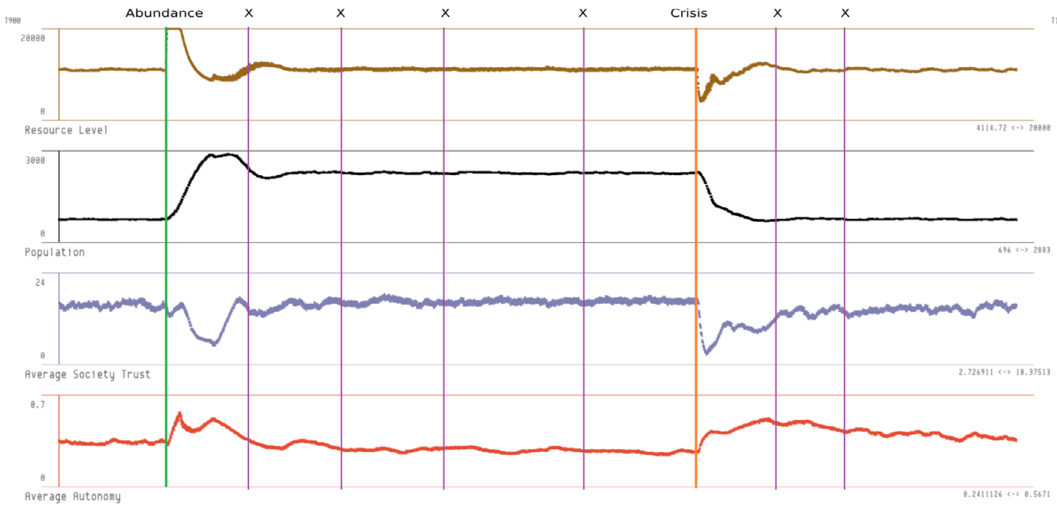

Figure 22. A sequence of external impacts in the weak cooperation domain with uniform nominal benefit distribution. External impacts are represented by green and orange vertical lines. Vertical lines denoted by X's mark the moments of switching between social conventions.

We use the uniform nominal benefit distribution corresponding to arbitrary social conventions for this test. Figure 22 shows a timeline of 900 years containing the external impacts. We can see a number of delayed changes to the dominant conventions after each external impact. These marked instances of changes in conventions represent the moments when the new social conventions become more predominant than the old social conventions.

However this switching of conventions is in fact a gradual process during which both conventions exist alongside each other. This process results from the interactions between divergent strategy blocks as depicted in Figure 23 and explained as follows: The process of gradual convention change is possible in the existence of an older and more autonomous generation $\mathbb{G}_A$ and a following younger and more social generation $\mathbb{G}_S$. For more clarity, let us denote the in-between generation by $\mathbb{G}_{A+S}$ that is the set of individuals who are in the younger tail of $\mathbb{G}_A$ and the older tail of $\mathbb{G}_S$ which overlap.

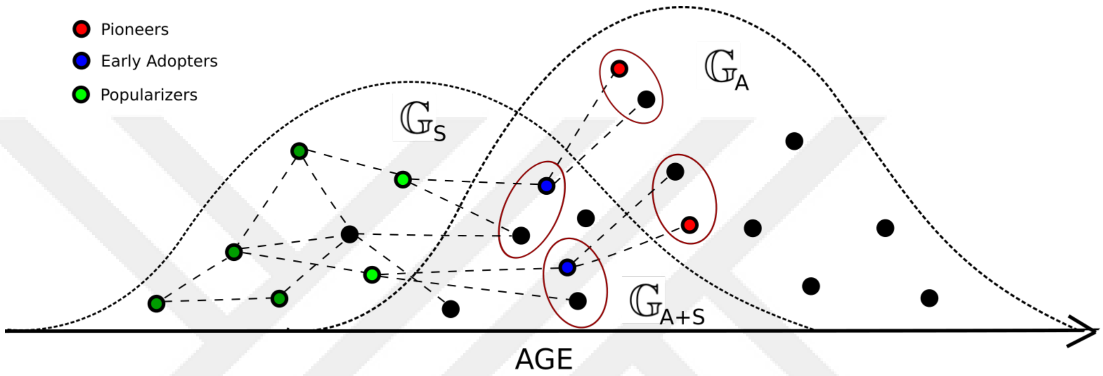

Figure 23. Gradual change of social conventions and the roles played by some individual groups designated as pioneers, early adopters and popularizers

In the autonomous generation $\mathbb{G}_A$, there is a larger intra-generation variance in action choices. This variance in choices tends to weaken the favorability of the dominant social convention but does not cause an alternative social convention to gain inordinate favorability. Whereas the individuals in $\mathbb{G}_{A+S}$ have social ties to particular subsets of individuals in $\mathbb{G}_A$ and they selectively sample world models from its most reliable members. The world models of a limited set of pioneers might favor an action alternative to the dominant convention. As $\mathbb{G}_{A+S}$ contains similar numbers of individuals who are autonomous and individuals who are social, in turn $\mathbb{G}_S$ samples the world models from this mixed-strategy set. This means that individuals in $\mathbb{G}_S$ abide by both the old and the new social conventions. This improves the favorability of the new convention in the society. As a result, more members of $\mathbb{G}_A$ pick up the new convention further strengthening it and consequently even more members of $\mathbb{G}_S$ switch to the new convention. This pattern of strategy blocks allows an accelerated change in the action frequencies as the social block $\mathbb{G}_S$ adopts the new convention as a coordinated ensemble.

The behavioural differences between individuals of these adjacent groups is highest at the moment of the societal switching of the dominant convention where individuals younger than the age center of $\mathbb{G}_{A+S}$ appear to have accepted the new convention and older individuals still appear to support the old convention. This is a generational difference in action choices. In our aspatial and single action domain worlds, this is a temporary situation but in the real world there are certain socio-structural mechanisms that would result in the stratification of this situation. These mechanisms will be discussed in detail in section 6.5. In the domain of strong cooperation, the effect of the alternating divergent strategy blocks is not strong enough to cause a change in the dominant social norm. In fact, the pattern is sustained for a much shorter time. We can see this comparison in Figure 24.

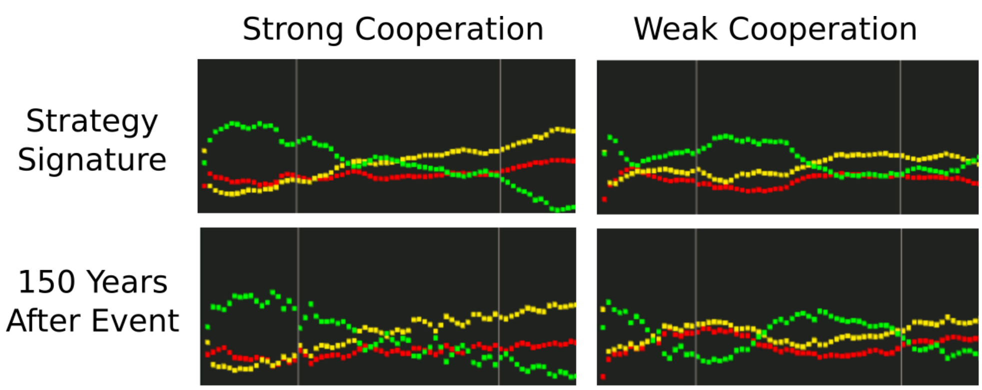

Figure 24. Comparison of the strategy states of societies in strong and weak cooperation domains 150 years after an external impact

In Figure 24, 150 years after the external impact, the strategy state of the society in weak cooperation domain still has alternating strategy blocks while strategy state of the society in strong cooperation domain has already converged back to domain's strategy signature. This can be interpreted as the following: Not only strong social norms persist under changing conditions but a strong cooperation domain causes the strategy state to display a shorter transient phase, blocking potential changes in other domains which might exist alongside this domain.

Other domains with positive frequency dependency display characteristics which interpolate between the characteristics of these examples of weak and strong cooperative domains. Stronger frequency dependency implies a shorter transient period after the external impact and harder to change social norms or conventions. Extremely small frequency dependency on the other hand results in very unstable social conventions resembling fashion trends which need neither an external impact nor regular fluctuations in the strategy state to change.

6.4.2 Competition domains

We define competition domains as the action domains with negative frequency dependency. The defining feature of these domains is that optimal choices change frequently and they represent opportunities. In the case of weak competition, these opportunities are marginally favorable and in the case of strong competition they are significantly favorable and they change more frequently. In Figure 25, we can see the nominal benefits, cumulative performance frequencies and actualized benefit returns of actions in some example domains of these types in the equilibrium state of the population.

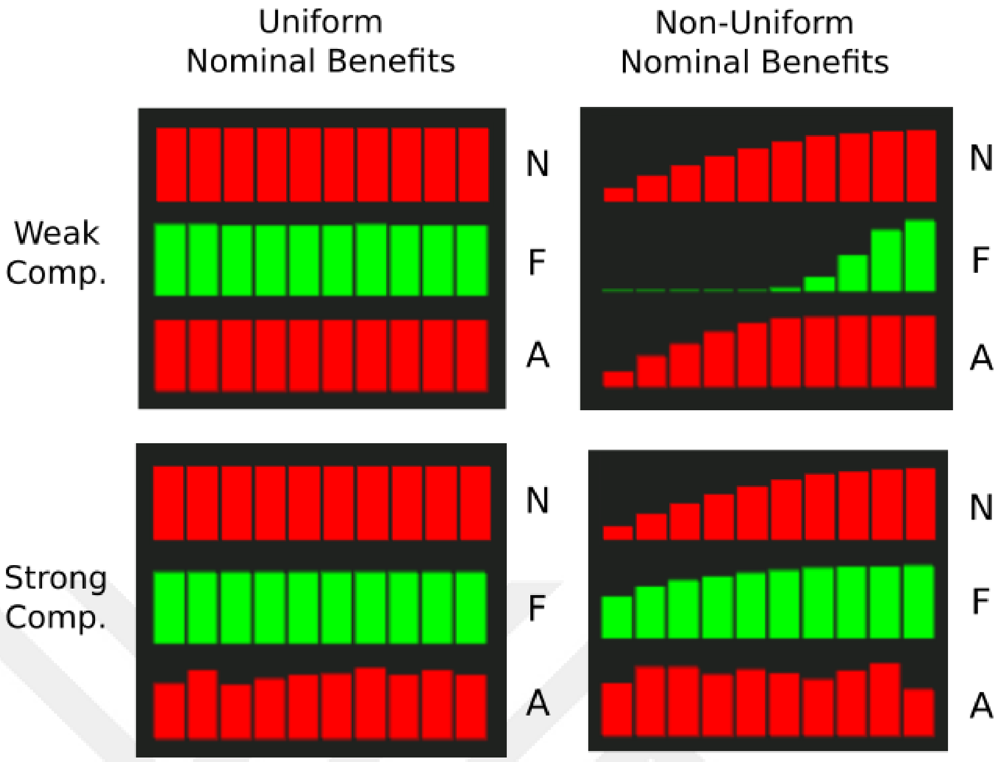

Figure 25. Benefit values and cumulative frequencies of actions in competition Domains. (N: nominal values, F: cumulative frequencies, A: actualized values)

It can be seen from figure 25 that in weak competition domain with non-uniform nominal benefits, some of the nominally better actions become frequently performed while in the case of strong competition even the nominally worst actions are performed with frequencies proportional to their nominal returns. In strong competition, actualized benefit returns display greater time variance as well as value variance among alternatives.

A comparison of some strategy states of weak and strong competitive domains can be found in Figure 26. Individuals of societies in weak competition exhibit very high autonomy except for babies and children and social strategies do not fare well. In strong competition domains, after a social adolescence, young adults tend to favor the spontaneous strategy since a tip from a stranger is quite valuable in order to seize a fleeting opportunity. However, none of the strategies are dominant in the strong competition domain because of the pace of change in benefit returns. In fact, much stronger competition domains can become so chaotic that only a few lucky individuals are able to live long and prosperous lives. Strategy states of strong competition domains reflect this ambiguity.

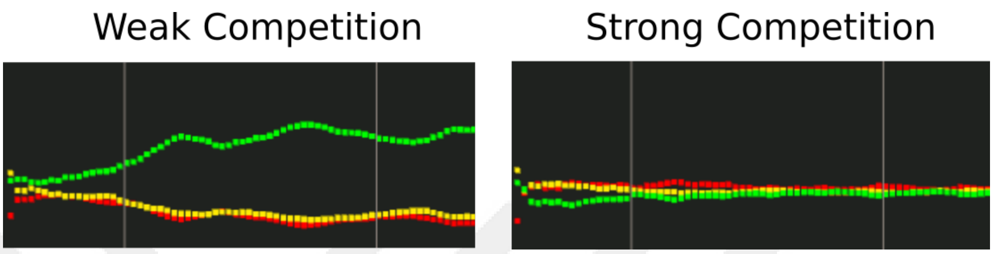

Figure 26. Strategy states of the weak ($f = -.001$) and strong ($f = -1$) competitive domains display different characteristics.

Competition domains have another very interesting feature. Stochastic variations in decisions, wealth and trust can cause demographic changes without external influence. This can be interpreted in the following manner: Strategy signatures of the competitive domains are unstable equilibria. Individual interactions in the society can randomly result in flocking towards a particular action among alternatives. When this happens, strategy state of the society can diverge significantly from the strategy signature of the domain. In strong cooperation domains, this flocking happens very frequently indeed but does not affect the strategy state of the society which arises from a much slower dynamics. Whereas in weak competition domains, this effect is not strong enough to cause much demographic change, so the strategy signature is not perturbed by much.

However, there is a certain degree of competitiveness which interacts significantly with the strategy state of the society. This is possible for competition domains in which the opportunities arise slowly enough that small groups can accumulate confidence in a social strategy, but not much more slowly than this, since the social strategy block only benefits from this opportunity for a limited time. When this condition holds, we can occasionally observe smaller but persistent social strategy blocks which form the pattern of alternating strategies we observed in previous domains. As we saw that this type of pattern can reproduce itself for a limited time, depending on the consequent stochastic choices of the society, the pattern can be amplified or repressed during this period. If the former happens, this may result in the emergence of sequential divergent strategy blocks which signal the onset of a generation gap. Figure 27 shows the fluctuations of average autonomy in equilibrium population societies operating in competition domains with various f.

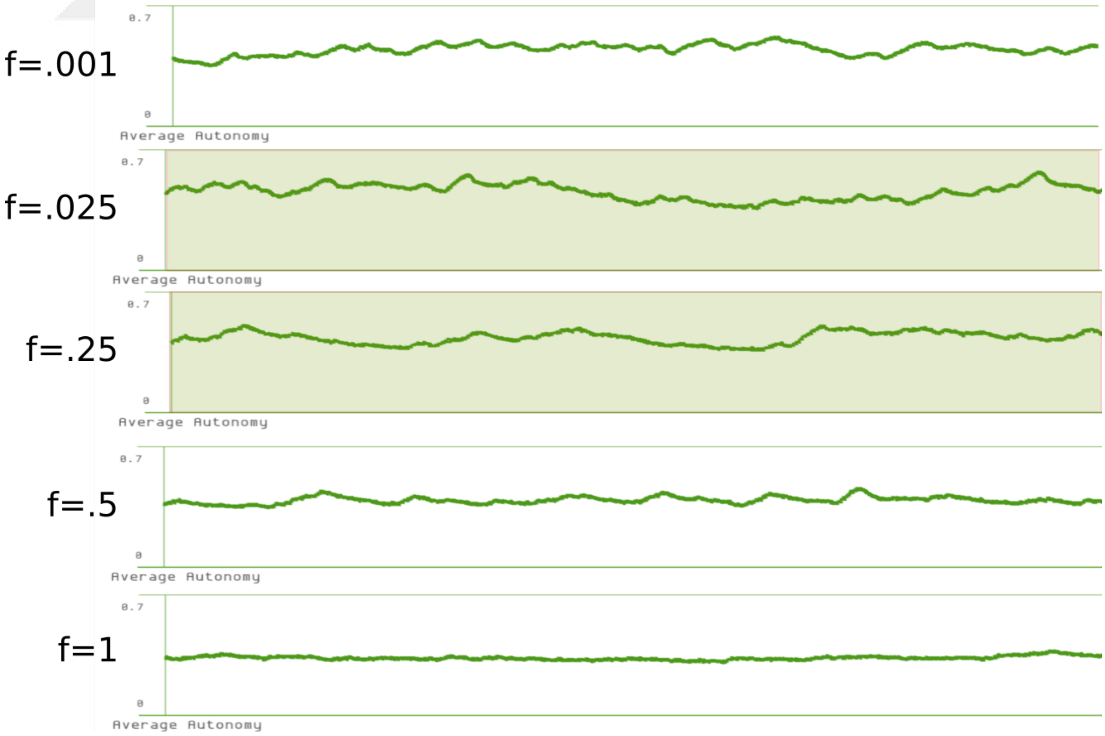

Figure 27. Self induced fluctuations of average autonomy in competitive domains for various values of f, highlighted domains exhibit slow and irregular fluctuations

Even though average autonomy fluctuations do not definitively establish the existence of self organization, it is a good indicator for this type of complex interdependency. Highlighted domains in Figure 27 exhibit slow and irregular fluctuations in the average autonomy. Note that this analysis is quite insufficient by itself to establish the existence of the complex behaviour we explained but we will not be able to pursue the investigation of this phenomenon any further in this thesis. The only conclusion we can draw at this point is that strategy states of competition domains may not have stable equilibria and that their strategy signature may not be well-defined.

External impacts affect the strategy states of competitive domains in a manner similar to other domains. Figure 28 shows the strategy states of a weak competition domain after two external impacts, a resource abundance and a resource crisis. Time intervals highlighted with green denote periods of abundance and time intervals highlighted with red denote periods of crisis. Note that a crisis of comparable effect lasts longer than an abundance because the population adapts to these events differently. In an abundance, the population increases reproduction more or less immediately, adjusting to the new resource levels. Whereas in a crisis, existing population only decreases by the natural process of stochastic accidents which takes longer. In both of the timelines in Figure 28, we can observe social strategy blocks even 120 years after the events have taken place. Regardless of whether they are formed as the result of perturbations caused by external impacts or induced by the self organized behaviour possible in these domains, these social strategy blocks are significant in competition domains in which autonomous strategy is seen to be dominant.

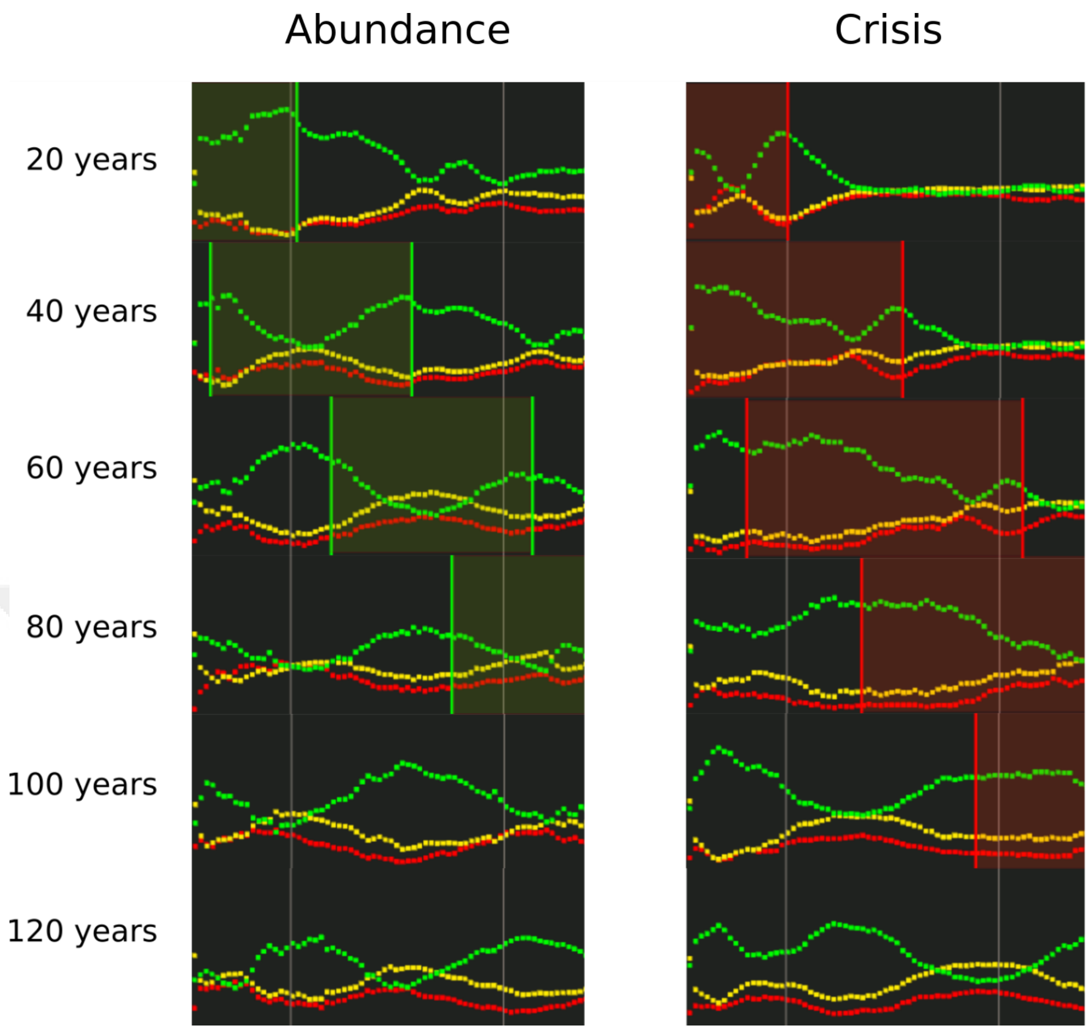

Figure 28. Aftermath of two external impacts in competition domains

We know that the actions performed by a block of social decision takers show less diversity than an equivalent autonomous block and the social strategy adapts more slowly to changes. Once we assume that at any moment this social group enacts some preference regarding the available actions which is disseminated over its council network and consequently performs a certain subset of these actions i.e focuses on a specific set of opportunities, this implies that the rest of the society must be focusing on the complementary set of opportunities at the time because of the underlying competitive dynamics and the fact that this social strategy block is able to persist. In other words when a social strategy block emerges in the competition worlds, the rest of the society who are predominantly autonomous adapts to the existence of this social block. By this reasoning, we can conclude that these social strategy blocks are highly likely to also act differently signifying generational differences between this group and the rest of the society.

We explained the conditions and mechanisms which result in the emergence of a group of individuals who use a decision strategy that is distinct from the rest of the society in competition domains. And we argued that this group is statistically likely to also focus on a specific subset of opportunities due to the fact that it exhibits less variability of action. Yet, admittedly the type of reasoning employed in the above paragraph does not exactly describe why a single individual in this group would behave differently than the rest of the society. Unfortunately in this more complex and dynamically rich domain, we can not provide a more mechanistic explanation here without loss of generality.

6.4.3 Beyond the abstract domains

In this section, we attempted to analyze two types of action domains with frequency dependency, each one equally interesting and distinct in operation. We chose to classify these abstract archetypes as pure domains of action. For clarity, this means a couple of things:

(i) Each action is assumed to resolve from the same implicit interaction dynamics. A rough analogy would be that all available actions can be considered as alternative moves in the same game, and conforming to the same ruleset.

(ii) The type of implicit interaction dynamics for an action is assumed to be the same, regardless of who or how many are performing it. To make use of the same analogy, this means that the rules of the game are invariant under participation and they do not change when applied to different individuals.

We had to make these strong assumptions to be able to discuss, in a sense, all human actions while hoping that insights about our abstract categories would be useful in understanding real human actions and real societies. However it is necessary to note some important differences between these ideal domains and real situations. In frequency dependent domains, cooperation and competition has special properties: Individuals participate equally in the cooperative social practice and they also benefit equally, and in competitive environments, all participants are equally rewarded. Also, the social norms which arise in PFD domains apply equally to everyone while real norms usually involve circumstantial exceptions. Therefore the behaviour of the model may differ from how real societies behave.

So let's consider a simple example to contrast with the societies in our model. Our example is a small tribal village where there are two possible ways to make a living. One can either collect fruits from the trees or go fishing to a nearby lake. Let's say that collecting fruit from the trees is ideally performed in collaboration with 10 people. This means that taking up fruit collection by oneself is not the greatest idea. On the other hand if too many people collect fruit, new groups must walk further to find the unpicked fruit. So let's say having more than 50 fruit collectors make everyone spend more effort to collect the same amount of fruit. To use our abstract categories, the interaction dynamics underlying the collection of fruit is

- Cooperative, if there are 1 to 10 collectors

- Neutral, if there are 10 to 50 collectors
- Competitive, if there are more than 50 collectors

Fishing however, can easily be done alone but there are only 10 good fishing spots and 10 bad fishing spots to be occupied by individuals. So the interaction dynamics underlying fishing can be considered to be

- Neutral, if there are 1 to 10 fishermen
- Mildly competitive, if there are 10 to 20 fishermen
- Competitive if there are more than 20 fishermen

We can see from this small example that not only can there be different interaction dynamics underlying the alternative actions in a domain but also that this dynamics changes according to how many people are participating in it. Yet, there is a silver lining to this comparison. Note that if this village has only 10 people, the action domain is essentially a cooperative domain with a nominally best action, the fruit collecting. If instead the village has 100 people, action domain becomes a competitive domain. If we make quantitatively clear what 'cooperative' or 'mildly competitive' means and we consider fish and fruit as commodities, it is possible to determine a domain type and adjust the relative nominal benefits for each population level of the village. This means that at least for a certain time frame, we can regularize the behaviour of some real human communities to conform to an equivalent model. In other words, our model can linearly approximate real societies.

Surely, there are much more complicated scenarios than this example and some of them can stubbornly resist an approximation or regularization of this sort.

However, it is important to note that stumbling on the technical limitations of a general model does not hinder us from applying detailed and particularist approaches where necessary. After all, we intended our general model to serve as an investigative tool for a specific phenomenon which manifests quite universally and to provide a specific kind of explanation of this phenomenon which must also be universal to a similar degree.

6.5 Generation gaps

We characterized generation gaps by the systematic differences in the behaviour of groups of individuals around distinct ages. We have seen that action, decision and trust mechanisms used by individuals with certain micro-properties result in the changes in some meso structures such as demographic distributions and special networks which in turn regulate these same mechanisms. We have also seen that some transient patterns such as alternating strategy blocks emerge as a result of either external influences or as a result of the interplay between micro actions and the meso structures, which in a sense, supervene upon these same micro actions and the micro properties of the individuals in the model. These transient patterns arise from the competition of decision tendencies within individuals and in the society.

In cooperation domains, we have seen that this type of pattern contains a certain transformative power over the social norms and conventions which are macro regularities of the domain. During this transformation, we have identified a certain moment at which a group of similarly aged individuals differentiate from the rest of the society in behaviour. Similarly, in competition domains we have argued that the existence of the pattern of alternating strategy blocks statistically implies a differentiation in behaviour for the individuals in social strategy blocks. In other words, we have established the existence of generational differences of action in both cooperative and competitive action domains that we have investigated.

In our model, these generational differences appear as transient emergent macro regularities i.e. they are formed, they persist for a short time and they disappear afterwards. Generational differences in the real world however, exhibit a more persistent character. Our model is unable to generate such persistently distinct generations because it does not include higher-level structures and mechanisms that enable the stabilization of generational differences by establishing distinct identities. Among such structures and mechanisms that can be relevant for generation formation, we can list a few:

(1) Segregated spaces: Age groups typically have very high degrees of intragroup connectivity due to the structured nature of social environments. Children play in parks together and go to elementary schools. Teenagers are concentrated in high schools and young adults occupy colleges and internship positions. In other words, there are structural reasons for individuals of similar age to get together. Once these groups adopt untypical conventions before everyone else as observed in our model, this results in even more intragroup cohesion and identification effects and sustains the structural isolation of generations.

(2) Group identification: Once a generation starts exhibiting distinct characteristics, these characteristics are reflected in a group identity. This identity is signalled implicitly by various individual preferences and attributes and explicitly

by particular overt social signs such as choice of attire, language, music taste etc. Group identities reduce intragroup differences and provide a perceived demarcation between the group and the rest of the society. This identity and its signalling not only modulates community building, trust formation and mating but also plays an important role in individual commitments and in the further structuration of group exclusive locales and activities.

(3) Age discrimination: Regardless of their behaviour, age groups are subject to discrimination. This does not necessarily arise from prejudice. People act towards each other according to schemes appropriate for an interaction between individuals of corresponding ages. There are accepted ways for an adult to interact with a child, and there are accepted ways for a teenager to interact with elderly. Even though these schemes tend to change, at any moment individuals in an age group usually experience social life through similar filters. This bolsters the age identities.

(4) Competence formation: People are changed by their actions and choices, they acquire skills, form habits and become more competent in their routines. This makes them more likely to subsequently engage in similar actions. Thus in real life, the consequences of divergent choices in the life of a person are much more persistent than in our model. Furthermore, the set of actions and choices are never fixed, actions come into being and actions become obsolete. Stone masonry ceases to be a viable career opportunity and software development becomes one. Once new opportunities are seized by a younger generation, they usually satiate the need for these new actions and their ‘professional‘ formation starts to define them. And once this happens, the generation not only shares a common typical educational

experience and so on, but also shares common interests and lifestyles due to their software developer careers or skydiving hobbies.

(5) Linguistic differentiation: Acquisition of language by different generations takes place in different cultural backgrounds. Language learners are influenced by contemporary television shows, buzzwords of the contemporary agenda and technologies. Because of these mechanisms and more, the language used by a generation also differentiates. They invent names for things that the rest of the society is unaware of, they use references that would be alien to most others and in extreme cases, they even employ a different grammar. This type of linguistic and semantic differentiation between age groups bolsters age identity which can be signalled overtly and results in even further disconnection from the other generations.

All of these structural mechanisms and effects add certain inertia to generation formation. Once a certain threshold of behavioural divergence among generations is crossed and this behavioural divergence is sustained for some time, these mechanisms that we have not modeled are more than capable of starting a process of further insulation which results in a persistent gap of generations.

To summarize, we identify three stages in the formation of generation gaps: (1) an age dependent divergence in tendencies we equated with decision strategies which occurs as a result of demographical/network changes interacting with individual decisions, (2) a temporary divergence of action choices which indicate generational differences in behaviour enabled by world conditions and the implicit strategy divergence, and (3) a generation gap which persists as long as the divergent generation exists as the generational differentiation of action choices interact with the existing social/cultural structures. Figure 29 informally depicts the explanation for the emergence of generation gaps as described in this thesis.

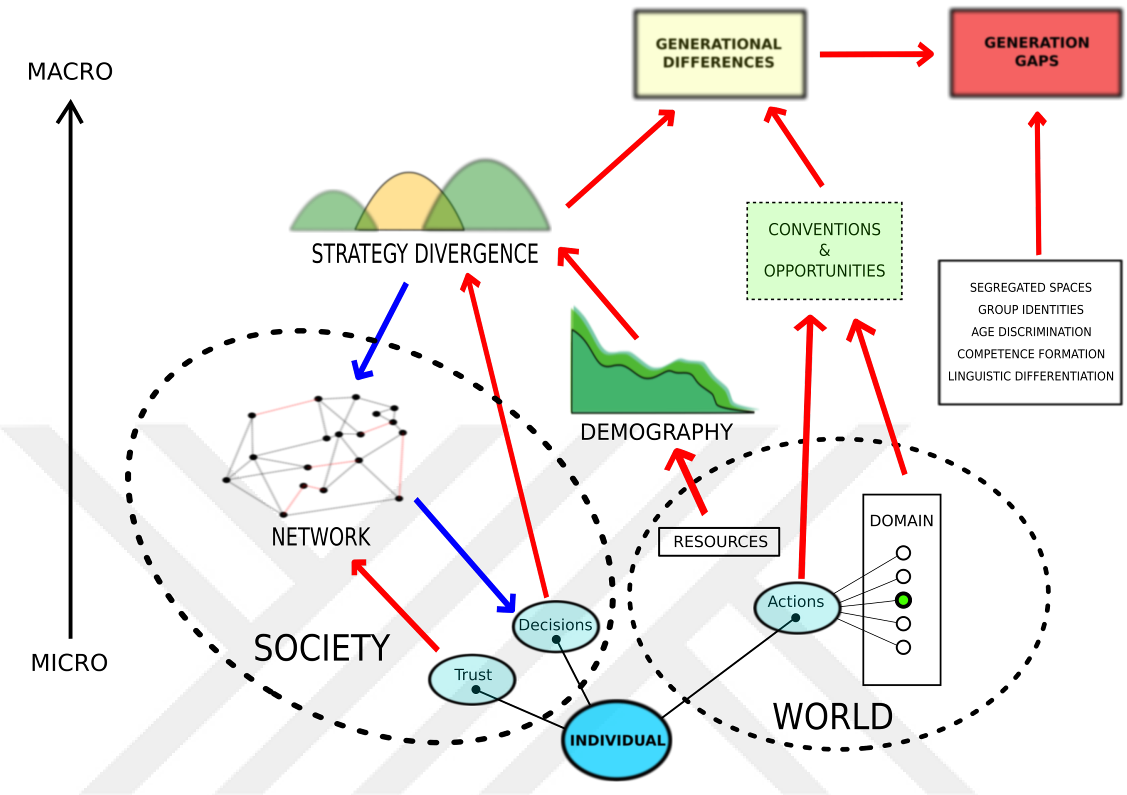

Figure 29. A graphic summary of the emergence of generation gaps as described in this thesis. Arrows denote the causal explanations

CHAPTER 7

DISCUSSION AND CONCLUSIONS

I started this thesis with two research questions: (1) Can we predict the emergence of generation gaps by observing the ambient historical conditions? (2) What can we infer about the historical conditions by observing a generation gap? It turns out that these questions suffer from an oversimplification of the effects of historical conditions. The basic findings of this study will indicate a better way of forming these questions.

7.1 Basic findings

First of all, we identified three stages in the formation of generation gaps. First stage is the emergence of divergent strategy blocks. Second stage is the behavioural differentiation of generations which results from these divergent strategy blocks. And a last step is a persistent generation gap which we were unable to observe in our model resulting from the stabilization of these generational differences possibly via interactions with unmodeled macro structures.

In our model, we saw that untypical periods resulting from external impacts do cause changes to the individuals experiencing them, but they are not immediately followed by a differentiation among different generations. However, these changes start a cascade of delayed network changes, which periodically prime the society for the emergence of generation gaps for some transient period which can sustain for centuries. The length of this period depends on the impact of the event and the type of social interaction dynamics underlying the actions of individuals. This finding is consistent with the historical observations about generations in that there is a phenomenon of circular nature playing a crucial part in the formation of generations and their divergence.

Emergence of this circular phenomenon of self reproducing divergent strategy blocks is strongly correlated with the major changes in the society or the world. Yet, some types of social interaction dynamics in our model which distinctly resemble the commonly observed types of regulated competition in modern societies are capable of bringing out these cascades of network changes by themselves, meaning that significant changes in macro properties of a society is not the sole instigator of generational differences.

Finally in our model, we saw that generational differences indeed have powerful transformative effects. We know that sometimes the existing social conventions can not be changed to better ones without some sort of intervention or regulation by macro-entities such as governing agencies or laws. Generational divergence makes the natural switching of the society to an objectively better social convention much easier. When such a divergence is accompanied by a competitive dynamics such as a choice of professions, we have seen that this may result in a systematic preference of the cohesive younger generation over particular choices. Considering that this younger generation is also likely to switch conventions and social norms, this could very well trigger qualitative changes to these particular professions of choice, or even paradigmatic shifts in specific fields.

7.1.1 Prediction of generation gaps

In the light of these findings, definitive prediction of a generation gap in the real world using historical conditions as anchors seems highly improbable because the generation gap may not immediately follow the untypical period and it might take many familial generations before a generation exhibits distinct behavioural characteristics. Furthermore, historical conditions of an era can not be laid out in an isolated form because in contrast to the controlled environments like our model, at any time, society is still affected by the periodical aftershocks of long past conditions. So the answer to our first research question remains in the negative, we can not predict the emergence of generation gaps by focusing on the historical conditions.

We can, however, estimate the likelihood of generational differences because the first stage of a generation gap can be identified more easily than the historical conditions themselves. What we call social and autonomous strategy blocks in this thesis manifest a number of symptoms that can be observed. When a younger generation displays significantly more intragroup social cohesion and harmony than the generation it follows, we can infer that this generation is likely to differentiate in the presence of potential new conventions or ambient opportunities. This differentiation is seen to be very useful as it has the power to transform the entire society but it is also the precursor to persistent generation gaps.

7.1.2 Interpretation of generation gaps

I had started this thesis under the impression that generational differences could maybe be avoided and that maybe I could identify some implicit feature of our societies as the culprit, but the insights from my investigation drastically changed these opinions. The society model I proposed was incredibly simple compared to real societies, still my findings about the working of this simple model revealed an entirely different perspective that I think is still sound when applied to reality: Generational differences may be fundamental catalysts to adaptation in populations and to its cultural evolution.

Changing material conditions of the world prompt a set of adaptive changes in the society. However, this societal change is not a slow and gradual process. Because of the existing equilibria of action dynamics, society may be fixated in its behavioural characteristics until the social condition of the existence of a younger and more social generation is fulfilled. This social generation commonly results from the elevated prevalence of autonomy accompanying the change in material conditions. The Behavioural characteristics of a society exhibit something similar to punctuated equilibria. The slower dynamics of competition between social and autonomous tendencies in individual groups allows the destabilization of these equilibria causing rapid changes to behaviour of the society. The presence of generational differences thus signifies that both material and social conditions have been fulfilled.

7.2 Critique

The society model employed in this thesis has certain shortcomings. Firstly, we assumed that all individuals take a fixed number of important decisions every year and their actions are synchronized, whereas real people's important decisions do not occur in uniform and timely intervals. We also limited our societies to a single context world. This might be useful in understanding the isolated baseline behaviour of the society in various domains like competitive or cooperative environments but it also cripples our working trust model. It is all too reasonable to assume that people may place trust in their peers in certain contexts and place their trust in older people in others.

We have not included the spatial aspects of the world into our model and settled for an approximation of their effects. One of the implications of this is that resources in our model are not tied to specific loci but instead assumed to be accessible from anywhere. This approximation is only adequate for smaller communities where mobility effects are negligible. In theory, this limitation can be amended by a conception of the larger societies as constituted by many smaller communities. Yet in order to pursue this approach, our assumption of closed population dynamics must be changed accordingly.

While the individuals in the model differentiate because of their parents and because they are embedded differently in the society network, they are still quite generic: They have no inherent properties or abilities that make them distinct. The assumption underlying this design decision was that if generational differences can arise with generic individuals, they can also arise with individuals with heterogeneous properties. Individuals also represent the world simply with a list of expected benefits and experiences and admittedly, this is a very a shallow conception of an individuals' understanding of the world. Not only that the world models of individuals lack causal principles or conditional knowledge as can be expected from a sensible world representation but also lack a model of the society. In short, our individuals may be too simpleminded.

7.3 Suggestions for further research

A comprehensive analytical investigation of generation gaps is hardly the material for a single study. Because of the wide breadth of components and factors relevant to our phenomenon of interest, we narrowed our scope with a limited selection of pilot components and we could only provide very limited analysis on each of these. In this form, this thesis can best be interpreted as an elementary guide for further research in this topic. For example, our conception of a spaceless world with abstract action domains was not suitable for certain types of investigations, a more in-depth investigation of social norms can be conducted by also taking into account their network locality in a segregated society. Similarly, our findings in this thesis are justified for smaller communities but a conception of human societies as collectives of such smaller interacting communities may bring about a more general paradigm to investigate the generational differences in modern societies.

We established some mechanisms which influence the emergence of generational differences in this model and ours is most likely not the only model in which some mechanistic explanations to this phenomenon can be given. Yet we could only offer some suggestions about how these generational differences might turn into generation gaps. A better analytical treatise of this process or a generative model would be invaluable to this research topic explaining how existent differences interact with socio-cultural structures.

7.4 Conclusions

Main contribution of this thesis is an account of generational differentiation and its sustainment by a micro-foundation of social relational mechanisms. These relational mechanisms arise from the society and trust formation principles of individuals and their embeddedness in these networks both of which stems from the social structural entity of the atomic family. The generative model of this thesis contributes to the literature on generations by providing a test bed for bottom-up causal explanations of their commonly observed macro features.

In particular, we explain the circular nature of generations by the inherent dynamics of strategy preferences resulting from social/autonomous tendencies of individuals. We also demonstrate some examples of the transformative power of generations over the social norms and in competitive environments. When considered in conjunction, the effects of generational differences in our two abstract domains appear to possess even more transformative potential.

Our model may be custom tailored to investigate generational effects but in its foundation lies a core agent based model of an adaptive networked society. With appropriate extensions, this core model can also be suitable for investigating other types of interesting research questions regarding voting behaviour, economic equality, sustainable societies, discrimination dynamics etc. So, the model proposed in this thesis can also be considered as a humble contribution to the growing literature on agent based methodologies.

Yet perhaps one of the accidental findings of this thesis may be of most importance since it independently verifies a well acknowledged opinion: Consequences of the historical moments reverberate in time along several life times. This does not only happen because the environment itself is changed, but also happens because historical moments may evoke dormant and implicit dynamics within individuals starting an era of unexpected consequences in the future generations. This finding has strong implications for the acts of policy making and political decisions in societies. So I choose to finish this work not with my own words, but with the timeless wisdom of the Iroquois instead. The Great Binding Law (Gayanashagowa) of the Iroquois Nation demands the following statement to be made to a prospective lord of the confederacy (Murphy, 2009):

> (...) The thickness of your skin shall be seven spans – which is to say that you shall be proof against anger, offensive actions and criticism. Your heart shall be filled with peace and good will and your mind filled with a yearning for the welfare of the people of the Confederacy. With endless patience you shall carry out your duty and your firmness shall be tempered with tenderness for your people. Neither anger nor fury shall find lodgement in your mind and all your words and actions shall be marked with calm deliberation. In all of your deliberations in the Confederate Council, in your efforts at law making, in all your official acts, self interest shall be cast into oblivion. Cast not over your shoulder behind you the warnings of the nephews and nieces should they chide you for any error or wrong you may do, but return to the way of the Great Law which is just and right. Look and listen for the welfare of the whole people and have always in view not only the present but also the coming generations, even those whose faces are yet beneath the surface of the ground – the unborn of the future Nation. (Gayanashagowa, 28)

APPENDIX A

PARAMETERS

Our model is not very sensitive to the changes in most of the selected parameters. On the contrary, wide ranges for the values of most parameters result in working models. However, we would like our individuals to exhibit the typical characteristics that can be expected of real individuals. This appendix explains the reasoning behind the selection of the values of our parameters.

A.1 Ancestors

Ancestors represent the initial population which produces our societies by reproduction. Typically 50 ancestors are capable of this, but the population reaches the equilibrium faster and more smoothly when there is more than 200 ancestors due to efficient mating. Even though it is possible to start with more ancestors than the equilibrium population, this is redundant since many of them would not be able to reproduce and temporarily hurt the well being of endogenously produced population.

A.2 Number of actions in the world

Number of actions in the world represents the number of alternative options the individuals have to consider at each action term and is an important parameter. Having less than 5 options usually results in too simple worlds which does not result in some of the high level regularities we wish to investigate and having more than 100 options slows the simulation significantly. We chose to set this to 10 because typically people can not evaluate more than this amount of action alternatives and when they are presented with more options they either use preliminary heuristics to systematically reduce them or they experience ‘option paralysis’.

A.3 Action terms

Action terms denotes the number of individual decisions taken each year. The type of decisions that warrant consulting trusted ones typically arises at most once in a few months. We used 5 action terms a year because this choice fits the above reasoning and frequent enough to allow for multiple decision strategy changes along a life time. A higher number of action terms in an action domain with 10 options results in individuals who become maximally competent too early in life.

A.4 Networking

With our choice of conservatism as 0.4, we are allowing a 60% chance that encounters result in meeting strangers. With an encounter period of 2, a person living up to 100 years old can be expected to acquire 150 acquaintances in life. This is a reasonable number. Typically people have more than this number of acquaintances but closely matching real humans in this aspect can be problematic because this could result in simulated individuals knowing a significant fraction of the simulated population whereas a real person usually can know a small fraction of the population. Community exploration parameter of 0.9 signifies that the individual and the others he meets have at least a shared acquaintance most of the time. Council size is the number of others from which the individual attempts to seek advice at each decision. In real life, people do not behave uniformly in this respect. A council size of 7 is about the maximum number of others a person employing social decision strategy can consult consistently and is able to factor in their opinions.

A.5 Health and accidents

Unlike qualitative characteristics visible in Figure 1, numerical values which determine the maximum health of individuals at each age are somewhat arbitrary. These parameters only matter in relation to the impact of stochastic accidents. With the chosen parameters, the worst accidents can twice kill the fittest individual and 10% of accidents are mortal regardless of the individual's health. Combined with the stochastic accident rate, this results in an accident related death rate of 0.5% for the entire population resembling real life statistics.

A.6 Reproduction and Parenting

The age interval of 18-55 is typical for parenthood. Fertility of 0.8 represents the success rate of baby making of the prospective parents. This means that couples who decide to have a baby can do so within a year 80% of the time and within 2 years 92% of the time and so on. Parental investment parameters are closely tied to living costs and should be able to allow the survival of children. A baby model's fidelity to parents' expresses how strong cultural imprinting is. A fidelity of 10 means that the action most frequented by the parents will be represented in the baby's model as equivalent to the baby having experienced this action 10 times. This choice of parameter causes the babies to simply mimic their parents even when not affected by their advices.

A.7 Trust

Dispersion coefficient must always be more than 1. A value of 2.5 for this coefficient allows individuals to discern more clearly between bad adviser and good advisers. A higher coefficient means that providers of bad advices are penalized more strongly.

A.8 Exploration

A maximum frequency of explorations of 0.1 means that 10% of the actions of the most exploration oriented individual are exploratory actions. The optimal value for this parameter is very dependent on the number of actions and the number of action terms. Provided settings result in a realistic learning curve of the world for the individuals.

A.9 Inheritance of wealth

These parameters are optional and only provide a realistic variance in individual wealth. Inheritance can be switched off by setting Efficiency to 0.

A.10 Decision strategies

Discrimination neighborhood denotes the necessary perceived superiority of a particular decision strategy that can be discerned by individuals. The value 0.2 resembles 20% difference in estimation accuracy. Having a lower discrimination neighborhood results in more frequent changes in dominant tendencies. We want this dominant tendency to change but not too frequently.

A.11 Frequency dependency

The salience weight used to adjust the time frame for the interactibility of individual decisions has been selected after careful deliberation. Frequency dependency which represents the nature of social interaction dynamics must account for quite a diverse range of phenomena. These include improved efficiency of facilitating conditions as well as ambient synergy between the actions of participants in cooperation domains, and counteraction dynamics, opportunity blocking and depreciation of facilitating conditions in competition domains. We have chosen α_ϕ to account for all these effects.

APPENDIX B

ANALYTICAL LIMITS FOR POPULATIONS

Let us assume that there is an individual called *oracle* who manages to choose the objectively best action among alternatives for all times. Life costs of the oracle like other individuals is given by $L(t_o) = b + c.t_o$ Wealth of the oracle at age y can be defined as follows:

$$W_{oracle}(y) = 2\mathbb{P} + (y - D)\beta - by - cy^2 \tag{B.1}$$

Where β is the average of the benefit return values of the best action during a period, $\mathbb{P}$ is the cumulative parenting cost and D is the development period for children. This function is maximized where $\dot{W}_{oracle}(y) = 0$. The y value that maximizes the wealth will be called the golden age, $y_G = \frac{\beta - b}{c}$. Now the necessary condition for the oracle to have at least two children can be given as:

$$W_{oracle}(y_G) \geqslant 2\mathbb{P} \iff \beta \geqslant Dc + b + \sqrt{D^2c^2 + 2Dbc} = \beta_0 \tag{B.2}$$

Similarly, the condition for the oracle to have at least 3 children is given by:

$$W_{oracle}(y_G) \geqslant 3\mathbb{P} \iff \beta \geqslant Dc + b + \sqrt{D^2c^2 + 2Dbc + 2\mathbb{P}c} = \beta_1 \tag{B.3}$$

These conditions define two values, β_0 and β_1 for the benefit levels of the world that are significant for the populations inhabiting it:

(i) If $\beta < \beta_0$, population will decrease and eventually extinction follows as not even a couple of oracles are able to replace themselves. β_0 is the theoretical lower limit for existence of populations, any world that consistently provides less than β_0 benefit does not allow a stable population.

(ii) If $\beta < \beta_1$, population can not increase, as even a couple of oracles can not help population growth. β_1 is theoretical lower limit for sustainable populations, any world that consistently provides less than β_1 benefit may allow an existing population to subsist but this population is vulnerable and destined for eventual extinction.

APPENDIX C

METRIC FOR RANK COMPETENCE

We assume that the world contains N available actions and the rank order $\underline{R}_i$ of an individual's world model is a vector representing the order of preferability of the available actions. The world model, $\{b_i(a,t), a = 1, ..., N\}$ can be ordered so the rank order of an action a can be defined as:

$$R_i(a,t) = Ord(b_i(a_x,t)), \forall x = 1, ..., N \tag{C.1}$$

We will denote $\underline{R}_i(t) = \{R_i(a_1,t), .., R_i(a_N,t)\}$ as the rank ordering vector of a world model. Similarly, actual benefit gain of an action a in the world $B^*(a,t)$ can be used to obtain the objective rank order of the world:

$$R^*(a,t) = Ord(B^*(a_x,t)), \forall x = 1, ..., N \tag{C.2}$$

With a suitable parameter $\alpha < 1$, the deviation of a rank order from the objective rank order can be defined as:

$$Dev(\underline{R}_i,t) = \sum_{n=1}^{N} \left(\alpha^n \times |R_i^{-1}(R^*(n,t),t) - n|\right) \tag{C.3}$$

Note that there exists a maximum deviation for any given $\{N, \alpha\}$ corresponding to the deviation of the worst rank order. If we assume that α is a small enough positive real number, this maximum deviation can be written as:

$$MaxDev = \sum_{n=1}^{\lceil \frac{N}{3} \rceil} (\alpha^n (N - 2n + 1)) + \lceil \frac{N}{3} \rceil \sum_{n=\lceil \frac{N}{3} \rceil + 1}^{N} \alpha^n \tag{C.4}$$

Now the rank competence of a world model's rank ordering vector $\underline{R}_i$ can be defined as the following:

$$Competence(\underline{R}_i(t)) = 1 - \left(\frac{Dev(\underline{R}_i)(t)}{MaxDev} \right) \tag{C.5}$$

With this definition, $Competence(\underline{R}_i(t)) \in [0, 1]$ for all individuals. An individual whose order of preferability according to his/her world model matches the objective order of preferability of actions attains the maximum rank competence of 1.

APPENDIX D

CLUSTERING DATA

Figure D1 shows the characteristics of the generated equivalent random networks which are compared to the simulation. This data is used to assess the clustering properties of the emergent networks extracted from the simulation.

Pop	K-R1-Trans	K-R1-Cycle	K-R2-Trans	K-R2-Cycle	K-R3-Trans	K-R3-Cycle	C-R1-Trans	C-R1-Cycle	C-R2-Trans	C-R2-Cycle	C-R3-Trans	C-R3-Cycle
939	29816	9836	30388	9849	30173	9914	319	108	276	130	294	102
1224	11700	3710	11769	3591	11552	3691	309	122	267	118	307	108
828	22080	6979	22249	6918	22329	6990	287	112	279	103	301	109
1207	12165	3653	11817	3680	11794	3628	264	129	315	116	299	104
960	7424	2033	7455	2086	7374	2164	256	126	304	114	306	102
2037	5643	1606	5538	1623	5713	1584	286	113	288	131	300	127
2455	10841	3349	10868	3344	10848	3396	290	116	281	125	277	141
2233	36286	11745	36064	11610	36444	11704	301	121	272	108	290	95
1618	15847	4619	15981	4474	15708	4473	287	122	328	120	287	113
1913	6557	1796	6369	1818	6443	1766	311	92	293	116	301	115
2908	8474	2344	8287	2372	8334	2424	257	115	337	116	306	116
3550	11601	3565	11673	3515	11754	3664	305	97	302	122	249	112
3717	20114	6270	20059	6410	20058	6341	263	104	290	98	298	131
3296	31717	10336	31793	10414	31990	10569	273	95	274	117	301	119
2654	21476	6763	21206	6575	21447	6954	296	116	281	120	264	93

Figure D 1. Complete data of the clustering information in equivalent random graphs

Comparison of properties of the social network and the equivalent random graphs can be seen in Figure D2.

Pop	K-Trans	K-Cycle	K-Trans X	K-Cycle X	K-R-AVG-Trans	K-R-AVG-Cycle
939	62338	11693	2.07	1.19	30125.67	9866.33
1224	64035	6709	5.49	1.83	11673.67	3664
828	59750	10007	2.69	1.44	22219.33	6962.33
1207	61822	6457	5.18	1.77	11925.33	3653.67
960	34996	5484	4.72	2.62	7417.67	2094.33
2037	44588	4732	7.92	2.95	5631.33	1604.33
2455	71634	6453	6.6	1.92	10852.33	3363
2233	113904	15448	3.14	1.32	36264.67	11686.33
1618	58010	8906	3.66	1.97	15845.33	4522
1913	40544	5690	6.28	3.17	6456.33	1793.33
2908	69818	6979	8.35	2.93	8365	2380
3550	91063	7420	7.8	2.07	11676	3581.33
3717	100875	9972	5.02	1.57	20077	6340.33
3296	98536	13601	3.1	1.3	31833.33	10439.67
2654	64729	9348	3.03	1.38	21376.33	6764

Figure D 2. Complete data of the comparison between the social network in the simulation and the equivalent random graphs

Similarly, comparison of properties of the council network and the equivalent random graphs are summarized in Figure D3.

Pop	C-Trans	C-Cycle	C-Trans X	C-Cycle X	C-R-AVG-Trans	C-R-AVG–Cycle
939	1006	119	3.39	1.05	296.33	113.33
1224	1915	108	6.51	0.93	294.33	116
828	1251	110	4.33	1.02	289	108
1207	1861	114	6.36	0.98	292.67	116.33
960	1611	119	5.58	1.04	288.67	114
2037	2292	102	7.87	0.82	291.33	123.67
2455	2595	113	9.18	0.89	282.67	127.33
2233	1441	130	5.01	1.2	287.67	108
1618	1561	118	5.19	1	300.67	118.33
1913	1476	82	4.89	0.76	301.67	107.67
2908	2746	130	9.15	1.12	300	115.67
3550	3423	105	12	0.95	285.33	110.33
3717	1852	129	6.53	1.16	283.67	111
3296	1397	118	4.94	1.07	282.67	110.33
2654	1213	81	4.33	0.74	280.33	109.67

Figure D 3. Complete data of the comparison between the council network in the simulation and the equivalent random graphs

In all the figures in this appendix, columns whose titles start with ‘C’ are from the data of the council network and the columns whose titles start with ‘K’ are from the data of the knowing (or social) network. The columns which end with ‘X’ denote the ratio of the number of relevant instances in the simulation network to the average number of instances in generated random networks.

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