Maintaining Disparities: Analysis with a small evolutionary game model

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Prepared for the
29th International Conference of the System Dynamics Society
Washington D.C., USA, 24 – 28 July, 2011

Abstract

In an earlier System Dynamics Conference, the authors used a small model to illustrate oscillations in local responses to health disparities. It was noted that further work would address medium term trends and thresholds shaping public action to reduce disparities. This paper begins to address those issues using Heckathorn's model of 'The Dynamics and Dilemmas of Collective Action'. Among many other things the model illustrates the implications of hypotheses related to the relative 'fitness' of voluntary action, reciprocity and sanctions. The hypotheses can be used to explore the concept of governance in a causal loop diagram adopted by the WHO Commission on Social Determinants of Health. The conclusion is that the model (a) provides a framework for analysing elite responses evident in decisions made and avoided by governance groups with duties to promote public health, and (b) has the theoretical depth necessary to be recognised as a 'canonical situation model' as proposed by Lane and Smart.

Introduction

This paper discusses the selection of a small generic model that can be used to analyse social dynamics associated with health disparities, in particular the influence of governance practices. The selection criteria include three themes comprehensively introduced in D.C. Lane's commentaries on System Dynamics modelling namely: using integrative social theory in System Dynamics (Lane 2001a; Lane 2001b; Lane and Schwaninger 2008); identifying reinforcing loops (Lane and Husemann 2002; Lane and Husemann 2008a); and, the value of creating a library of canonical situation models (Lane and Smart 1996). This paper addresses the first theme directly; links those comments to historical evidence of a reinforcing loop; and suggests that, as questions of feedback are addressed, the theoretical strength of the model will make it a candidate for recognition as a canonical System Dynamics (SD) model.

A previous SD Conference paper (Cody, Cavana and Pearson 2007) provided a rationale for using social theories advanced by W.G. Runciman and J.S. Coleman to model underlying trajectories in health disparities. That paper and the associated poster suggested that oscillations in local responses to health disparities could be interpreted as competing normative regimes and represented by an evolutionary two-by-two matrix based on strategies of dominance and cooperation (Cody, Cavana et

al. 2007:5). Three significant references have been introduced since that paper was written. Firstly, the World Health Organisation (WHO) published the report of the Commission on the Social Determinants of Health (CSDH 2008) which drew on Sen's strategy of 'Development as Freedom' (Sen 1999). Secondly, Runciman re-presented his theoretical framework (Runciman 2009). Both of those sources consolidate and extend the earlier discussion. The third and most significant addition is a model developed by D.D. Heckathorn (1996; 1998) which seems to be directly applicable to the modelling issues identified by Lane and to the substantive problem of health disparity as defined by the CSDH. Regardless of the success or otherwise of this attempt to use the model, Heckathorn's model is a very significant contribution to the use of evolutionary games for sociological analysis. As far as we know, the potential of the model has not been widely recognised.

This project is using 'the five phase process of systems thinking and modelling' described by Maani and Cavana (2007:17) by progressively including more phases as model development continues. One objective is to select a small model (Rahn 2005; Ghaffarzadegan, Lyneis and Richardson 2011) that captures the main features of relevant, current social theory. That is, to locate in Lane's integrative dynamic an explanation for the existence of a public norm that treats reducing health disparities as a collective good, and, in that context, account for the distribution and stratification of social determinants of health. Heckathorn's model does this. Later phases of the project will complete the work programme outlined above by incorporating feedback that simulates changing normative regimes, and testing the validity of the model in structured discussions and with empirical comparisons. The validation of the model will focus on contribution to and defection from governance practices that apply a public norm of impartiality in decisions that affect the distribution of 'freedom-based capabilities', particularly decisions directly related to young children (Sen 2009:234).

The paper has four major sections. The first is an overview of generic theory used to generate hypotheses that relate social constraints to population health status. The commentary here suggests modifications to and inserts examples in Lane's Integrative Approach (see Figure 1 below), in particular emphasising interaction (rather than action), elaborating on the core concept of 'replication', identifying an explanation for the emergence of relevant social norms, suggesting that corporate actors are the source of relevant hierarchies, and consequently, concluding that governance practices are useful indicators of elite responses to disparities.

The second section outlines Heckathorn's small evolutionary model of 'The Dynamics and Dilemmas of Collective Action'. The main features introduced are: the payoff matrix and production function; the social state-space created by the ratio of Value to Cost and the exponent that represents the production function; and, the association of game structure and ideology, thereby providing a framework for classifying governance strategies that contribute to or defect from production of the collective good. The third and fourth sections present hypothetical scenarios which compare the levels of collective good produced in different settings. Two sets of strategies are illustrated. The first set consists of voluntary contribution and defection; the second adds a third strategy, reciprocity, and illustrates how the payoff matrix can be extended. Finally some concluding comments are provided.

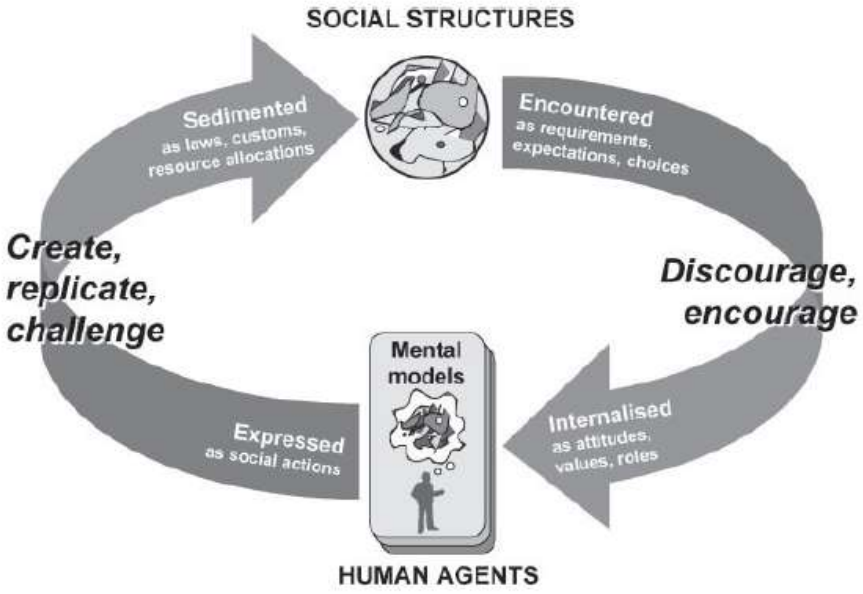
A Conceptual Framework

A Generic Approach

The first objective of the project was to identify a generic conceptual framework that could be used to: organise the range of variables that commonly appear in discussion of health disparity (e.g. Cody, Cavana et al. 2007:4 Figure 2); provide consistent guidance when observing social interaction related to specific issues in diverse settings; and, compare the effectiveness of claims for social equality with those that maintain a gradient of social ranking. Lane addressed this requirement in the context of System Dynamics modelling. He suggests social models should be based on a consistent, integrative approach to the dynamics of human agency and social structure (2001a; 2001b). He draws from a set

of broadly similar theories, emphasises the value of Gidden's 'structuration[1] theory' (Lane 2001b:297), and, with Husemann, proposes the scheme they summarised in Figure 1.

Figure 1: Feedback Implied by an Integrative Approach



(Lane and Husemann 2008b:55)[2]

We adopted this concept of an iterating process of replicating social practices, selected at least to some extent by endogenous structural pressures. In this paper the pressures are modelled as constants; feedback loops will be added at a later stage.

The rest of this section outlines five steps taken to adapt the approach defined in Figure 1 so it can be applied to the orientation of elites, evident as interactions among institutionalised roles that influence corporate constitutions and strategies. The five steps are: moving the focus of analysis from action to interaction; providing a high level definition of *social* and *dynamic*; sketching a social environment that can plausibly maintain norms of social equality, at least on some dimensions; introducing corporate actors as a primary source of social hierarchies; and, providing a rationale for regarding impartial governance as a public good that can reduce health disparities.

Social Interactions

Following Giddens[3], Figure 1 emphasises the mental models of individuals. This introduces a level of detail which is not required in a small model. It is more useful to focus the analysis of social systems

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1 Giddens suggests the appropriate way to analyse the constitution of social systems, 'especially "societies"', is to distinguish *structures* ('rules and resources, or sets of transformation relations' – also referred to as organising principles, institutions and interpretive schemes) and *systems* ('reproduced relations . . . organized as regular social practices' – both routine and motivated). He refers to the conditions governing the continuity of structures and reproduction of social systems as *structuration.* (Giddens 1984:25).

2 For a similar scheme using the additional concept of 'attractor' see Woog, Cavana, Roberts and Packham (2006 Figure 3). The focus in this paper is on three concepts from that framework: Power; Emergent Strategies; and Human Activities. The concept of Attractor has not been addressed explicitly here. For sociological discussions of the concept see Sallach (2000) and Mackenzie (2005).

3 After invoking Giddens as an authority, and having regard to the approach taken here, it should be noted that he has emphatically opposed the use of evolutionary concepts to explain historical processes. However, with strong reservations, he allows a place for modelling because 'there is no doubt that game-theoretical models can be very useful in empirical research, in respect of suggesting both

on interactions that reproduce relevant relations (Crossley 2011:129). A single human agent is not a social unit. Runciman discusses the replication of social practices and makes the point that:

> 'In the application of selectionist theory, as a leading evolutionary game theorist has aptly put it, "it is the strategies that come to the fore; the individuals that implement them on various occasions recede from view (Skyrms 1996:10)"'. (Runciman 2009:30)

Coleman came to a similar conclusion, which is in some ways more interesting because of his strong commitment to rational action theory and methodological individualism (Coleman 1990:5)[4]. After extensive work on a linear model of rational action included an assumption that social structure can be derived from an analysis of the purposive action of individual actors[5] Coleman concluded:

> 'In a double-contingency situation, where the very definition of what constitutes rationality is population-contingent, the notion of rationality is of questionable value as either a prescription for a course of action or a description of the course of action that individuals take. . . . In such a circumstance the idea that strategies can evolve through a process of selective survival is a highly appealing one. Evolutionary processes may not lead to an optimal strategy in a given population, but they will result in strategies that do well in that population. Because the strategies of all in the population are changing through the same evolutionary processes, the adaptive process constitutes a reasonable way to track the social environment. . . . For these reasons the development of theories of evolution of strategies appears particularly promising for double-contingency situations in social systems.' (Coleman 1990:931)

That is the approach taken here. The main issue becomes the survival, extinction and co-existence of social strategies. It seems to be a move towards an integrated system, as envisaged by Giddens, in which macro features ('selective pressures') and micro action ('replication') are aspects of the same process.

Social Dynamics

Runciman provides useful working definitions of *social* and *dynamics*. He has proposed a comprehensive scheme for analysing the replication of social practices and distinguishing social activity from other evolutionary processes. Runciman perceives a common logic in biological, cultural and social dynamics, namely 'heritable variation and competitive selection affecting phenotype'. (In this context a social role is regarded as a phenotype.) He identifies three levels of selection: natural selection of *evoked* behaviour, where the response to the environment is direct and instinctive; cultural selection of *acquired* behaviour where the response is imitated[6] or learned; and social selection of *imposed* behaviour associated with a social role underwritten by institutional inducements and sanctions (Runciman 2009:8). Runciman's scheme is reproduced as an Influence Diagram in Figure 2. The references to 'genes' and 'memes' are indicative and do not define the full scope of the influences involved. The diagram suggests that biological and then cultural factors create parameters for social practices, and that subsequently social practices might modify those parameters.

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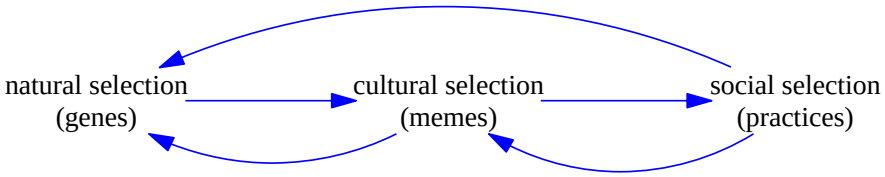
problems to be investigated and how research results might be interpreted'. (Giddens 1984:313) Nonetheless he regards it as very unlikely that sociologists will limit their interest to closed systems in which all significant causes of change are endogenous, where unique exogenous influences do not have a significant effect, or to processes where all other things can be considered equal (see also Richardson 2011). Secondly, Giddens asserts that social time is not measurable as chronological time. The duration and sequencing of the episodes of interest may vary greatly in each particular case. These are important considerations when reading model outputs.

4 Lane notes Coleman's contribution to formal theory (Lane 2001b:301).

5 Coleman is often cited as a prominent exponent of methodological individualism (e.g. Crossley 2011:9) however he regarded his Linear Model as equally applicable to actors or types of actor i.e. roles [Coleman 1990]

6 We assume humans have an innate capacity to *imitate* and *compare* which is strongly influenced by the *learning* environment, particularly emotional responses (Jasso 2006; Turner 2007).

Figure 2: Three Evolutionary Processes: an influence diagram



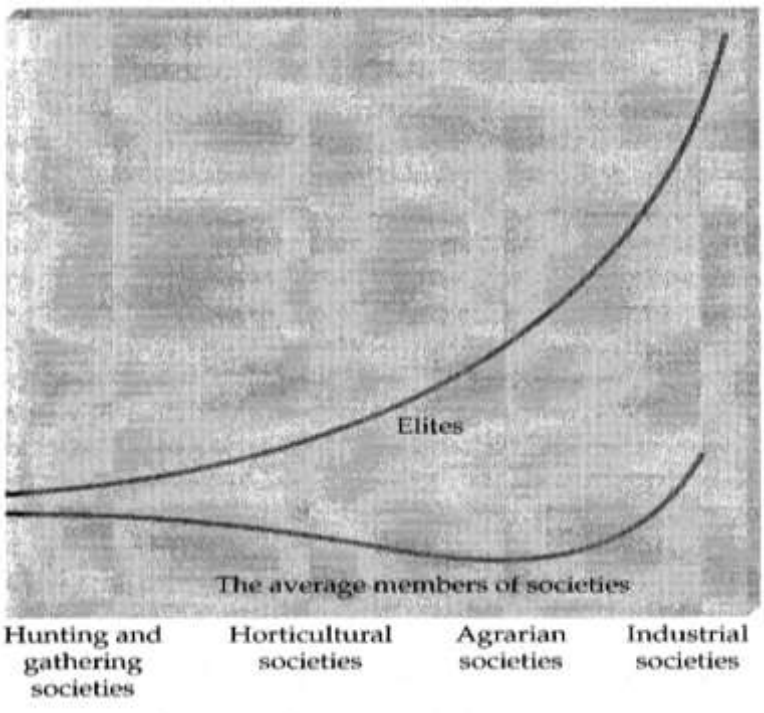
(based on Runciman 2009:224)

Figure 2 is used as a starting point for distinguishing and integrating the range of variables relevant to population health, and in particular to define the scope of the concept 'social'. This discussion is focussed on '*social* disparities', meaning stratified population health that can be attributed to social selection. Social selection is evidence of power on one or more of three dimensions: production, coercion and persuasion. Inequalities due to biological or cultural factors are excluded from this discussion. This approach leaves health outcome statistics open to considerable interpretation but does begin to structure discussion of how social stratification occurs.

Norms of Social Equality

Some account is required of the type of social environment that can: define inequality as disparity; sustain demands for reduced inequality; and, deploy sanctions that support those demands. Lenski provides a high level scenario of a context in which a power-weighted consensus might sustain an ideology of universal rights and strategies to reduce discrimination or inequality, loosely integrated with prevailing modes of production and coercion. Lenski's summary of a historical trajectory of 'freedom' is Figure 3.

Figure 3: Upper Limits of Freedom in Societies during the Holocene Epoch[7]



(Nolan and Lenski 2011:326)

[7] This is a passing reference to discussion of futures such as 'A man-made world' The Economist May 28th 2011 pp.81-83.

Figure 3 seems to imply one or more reinforcing loops of the kind Lane discusses. In this case factors influencing elite freedom have generated an increasing rate of increase throughout the epoch[8]. The Figure also identifies 'one of the rare instances in sociocultural evolution in which major technological advances generate negative feedback' (Nolan and Lenski 2011:146). The turning point in the evolution of relations among elite and other social roles is attributed to the decline of relatively unproductive militarised agrarian social systems[9] when in competition with mercantile technology and institutions, and followed by nation-states with industrial modes of ('private') production and democratic modes of ('public') coercion and persuasion (Giddens 1981:182-91, 197). The transition from agrarian to industrial societies reversed a trend of increasing social inequality (Lenski 1966:437) and loss of average freedom[10].

If this or some other rationale can explain a trend towards increasing freedom[11] and decreasing inequality then advocates such as the WHO Commission on Social Determinants of Health (CSDH 2008) can plausibly assume increasing[12] average well-being[13] and prescribe an expansion of existing institutional arrangements. The unanswered question then relates to the dynamics that sustain the distribution of freedom implied in Lenski's scenario. Nolan and Lenski suggest that, on average, in industrial and industrialising societies the median level of freedom is above the mean (Nolan and Lenski 2011:308). This depicts a social structure with an integrated 'middle' class and a skew in the distribution of freedom that implies lower ranked members have relatively little and increasingly unequal levels of freedom[14].

Selecting and presenting data to support this point requires detailed explanations that will not be attempted here. However, for the sake of illustration, if we assume that social constraints are the obverse of 'freedom' then the New Zealand Deprivation (NZDep) Index can be used to illustrate structures of social constraint that have emerged during the process underlying Figure 3. The NZDep Index is calculated using nine household variables from data gathered in the national census and is reported for 'small areas' of 100 people resident in the same immediate locality. Residential stratification is sufficiently well defined for most households in each area to be in the same socio-economic position[15]. In socio-economic terms the distribution of the Index is skewed[16]; it does not

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8 The dominant dynamic of the epoch is characterised as management of capital summarised as $Economic\ Surplus = \frac{(Resources)(Technology)(Capital)}{Population\ Size} + e$ (Lenski 2005:80)

9 For a model of cycles in agrarian societies see Turchin (2003; 2006; 2009).

10 Nolan and Lenski recognise other societal trajectories, for example examples of 'democide' in authoritarian centralised states (Nolan and Lenski 2011:322). Civil wars, colonisation, and transportation are also absent from this account.

11 Lenski's definition of freedom (Nolan and Lenski 2011:325-6) is similar to Sen's 'freedom-based capabilities' referred to by the Commission.

12 We do not assume that members of the System Dynamics Society share this assumption (e.g. Meadows, Randers and Meadows 2004)

13 After reviewing the evolution of and fit between the biologically based propensities of humans and the structure of societies Turner and Maryanski (2008:315) conclude 'political democracy accompanied by dynamic markets offering choices about where to live and work are far more compatible with human nature . . . than any other societal formations since hunting and gathering'.

14 More work is required to relate that to indicators appropriate to materialistic regimes such as income (Wilkinson and Pickett 2009) and residential segregation (Salmond, Crampton and Atkinson 2008).

15 About an eighth of households have a different level of deprivation to the area in which they are located (Salmond and Crampton 2002). Jasso has provided compelling theoretical arguments that support the Deprivation Index as an indicator of the physical and mental health impacts of socio-economic factors (Jasso 2008).

16 Distribution of NZDep2006 scores with the NZDep2006 decile scale superimposed – high score is most deprived:

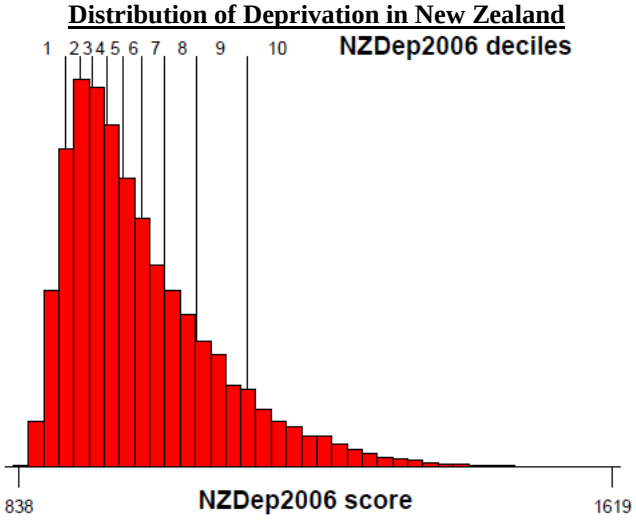
include indicators of affluence or wealth (Salmond, Crampton et al. 2008). Table 1 characterises a small nation (New Zealand) and city (Porirua) in the terms introduced by Nolan and Lenski.

Table 1: Structures of Social Constraint indicated by the New Zealand Deprivation Index

NZDep2006	New Zealand	Porirua
Mean	1000[17]	1060
Median	975	1065
Tenth Decile (upper limit of lowest ranked decile)	1140	1245

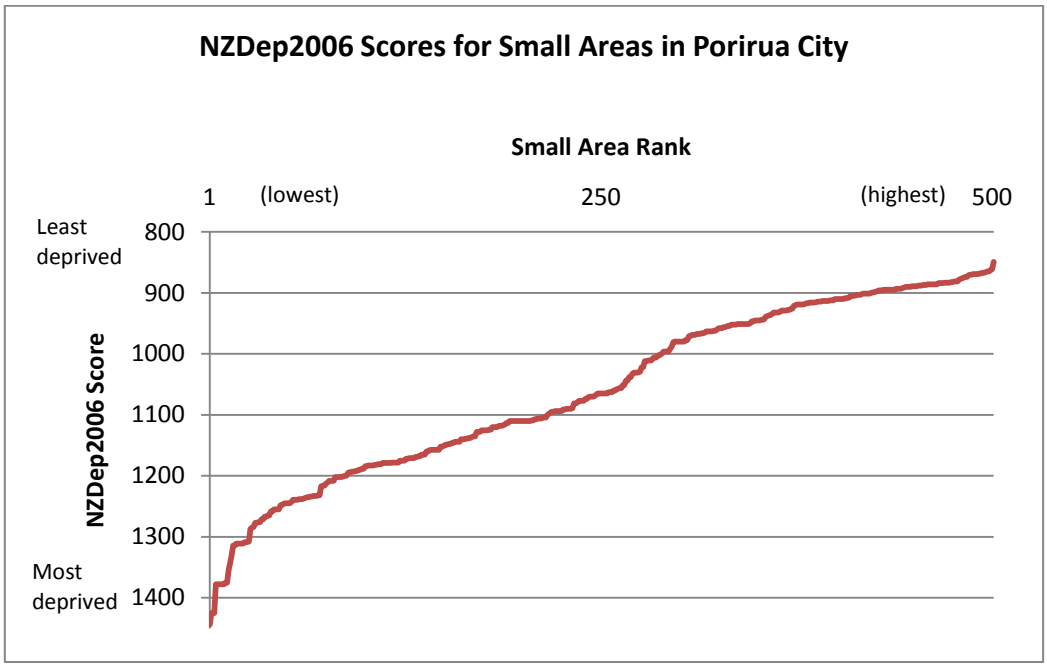
(Data from Salmond, Crampton et al. 2008)

Many reports note frequent and strong correlations between social constraint and health outcomes, commonly referred to as a 'health gradient' (Mackenbach and Kunst 1997; Wilkinson 2000; Marmot 2004; Blakely, Fawcett, Atkinson, Tobias and Cheung 2005; Blakely, Tobias, Atkinson, Yeh and Huang 2007; De Vogli, Ferrie, Chandola, Kivimäki and Marmot 2007). Two gradients are relevant: the general trend and the shape of the distribution for the deciles ranked most deprived. These are both illustrated in the data reported in Figure 4. We have interpreted the gradients as stratification of social constraint as an inverse of freedom.



[17] Normalised

Figure 4: A Distribution of Social Constraint



(Data from Salmond, Crampton et al. 2008)

Hierarchies and Corporate Actors

The trajectory of freedom of natural persons in industrial societies can be associated with increasing levels of population health. There is a parallel and closely associated process differentiating and increasing the influence of corporate actors[18]. This process has been a primary determinant of the distribution of health. There are three trends involved: increasing specification and differentiation of rights; a net transfer of rights of control from persons to abstract corporate actors (Coleman 1974; 1982); and, the relationship between rights and associated duties (particularly public and fiduciary duties), including processes used to mandate and sanction the discharge of those duties. Lane and Husemanns' (2008b:45-57) discussion of globalisation illustrates social interactions shaped by clusters of corporate actors and roles defined in relation to corporate entities.

Coleman (1990:546) drew a firm distinction between a natural person and corporate actor and proposed a two-by-two typology of interactions among the two types of actor (Coleman 1988:400-1). Applying the logic outlined above, 'natural persons' do not appear immediately in social analysis. The first distinction is between rights assigned to institutionalised roles allocated to natural persons and rights assigned to corporate entities. The objectives and practices of corporate entities may, at one extreme, be identical to those of a single natural person, or at the other not aligned with those of any natural persons (Coleman 1982:39-42; or 1990:554-6) having passed through various phases of diffusion, dilution and distillation. If Coleman's argument is added to the interpretation of Figure 3 then Figure 1 needs to include social selection pressures affecting corporate entities which then constitute the main sources of social 'encouragement' and 'discouragement' for interacting human agents.

Summarising this approach, the analysis of social hierarchies will be based on endogenous social pressures (power) influencing modes of persuasion, coercion and production that define: the form of organisations and institutional sectors; duties to recognise rights, and associated sanctions; and, two

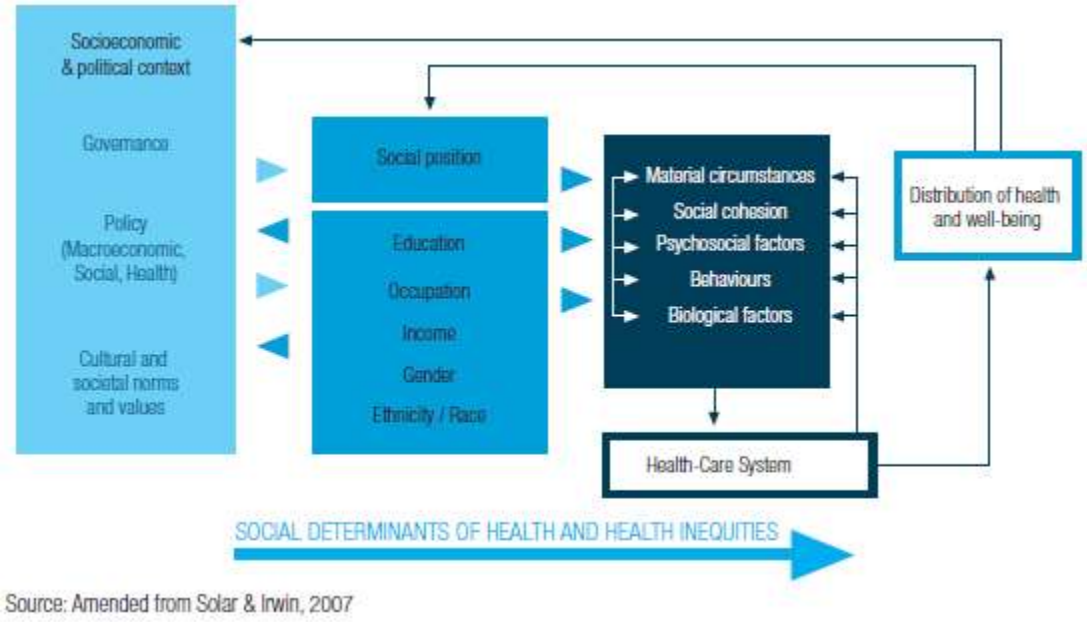
[18] Turner suggests industrial economies are characterised by reducing concentrations of wealth due to increasing numbers of hierarchies and organisations associated with increasing productivity (Turner 1984:93).

aspects of efficiency – the economy (cost) of maintaining social relations (Coleman 1990:426-35) [19] and ability to influence the operating environment (Coleman 1990:800). Beinhocker (2005; 2006) has provided a full outline of the logic in terms that are relevant to the management orientation of System Dynamics modelling using a Corporate Business Plan as an example of a core set of practices or strategies[20].

Impartial Governance and Health Disparity

The interactions of these types of influence are evident in governance processes. The Commission on Social Determinants of Health (CSDH 2008) included governance as a significant factor among social determinants of health, see Figure 5:

Figure 5: CSDH Conceptual Framework



(CSDH 2008:43)

The Commission says very little directly about feedback[21] or governance. An earlier discussion paper makes a passing reference to forestry management regimes that seem to be related to 'governing the commons' (Ostrom 1990). However A.K. Sen was a member of the Commission and the approach he takes in 'Development As Freedom' (Sen 1999) is endorsed at three points in the final report. Consequently it seems reasonable to assume that there is some continuity between the Commission's approach and the more explicit arguments in 'The Idea of Justice' (Sen 2009)[22] which proposes 'impartial reasoning' as a public norm that is critical to reducing disparities in 'freedom-based capabilities' and hence health. The norm can be regarded as a public good, similar in principle to property rights. That strategy has been adopted here. A subsequent paper will review the implications of the strategy with reference to hard cases, for example prohibiting social pressures that harm children and defining justifiable violations of the norm (Gert 1995:122-3) by examining cases selected with reference to Jasso's Comparison and Justice functions (Jasso 2005:35; 2008:10).

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19 This includes the allocation of rights within organisations (Coleman 1993).

20 More generally this is the 'social capital' invested in norms and organisations (Coleman 1990:310-3). Collins provides a useful perspective on Coleman's research strategy including a suggestion that rational action assumptions are more applicable to 'meso' and 'macro' dynamics than 'micro' interactions (Collins 1996).

21 Presumably the loop must relate to information rather than influence because the loops all pass through Health-Care System although other systems are also implicated (Beckfield and Krieger 2009:2).

22 Runciman and Sen (1965) jointly provide an example of this modelling strategy.

Development of a small Evolutionary Game Model

Overview

Heckathorn has created a small, generic model of 'The Dynamics and Dilemmas of Collective Action' (Heckathorn 1996) that addresses the issues raised in the previous section. The model is based on the two-by-two payoff matrix of a basic evolutionary game formed by two strategies, one of contribution to a collective good and the other of defection. Heckathorn supplemented the matrix by, firstly incorporating a production function which can, among other things, be used to simulate elite responsiveness, and secondly, adding strategies that simulate selective sanctions. The modelling strategy is an extension of one used by Hirschleifer and Martinez Coll (Hirschleifer and Martinez Coll 1988; Hirschleifer 2001). Gilbert and Troitzsch (2005:32-45) provide a System Dynamics representation of an early version of the model based on Maynard Smith's Hawk-Dove-Bourgeois game (Martinez Coll 1986)[23]. To this point validation of the model below has been limited to replicating Heckathorn and Martinez Colls' (1986) published outputs. We have not had direct access to the models.

The model uses generic variables to generate an extensive range of theoretically informed Behaviour Over Time. Initially Heckathorn used the model to depict trajectories of successful social movements. Subsequently Centola and Heckathorn suggested the approach can be applied to other systems of collective action (Centola and Heckathorn 2010:7). '[I]t is possible that our use of structural incentives to analyze the maturation of social movements may be applied to a wider range of organizational trajectories. . . . Our analysis of the micro-incentive structures of collective action may be easily generalized into a model of the dynamics of organizational development, transforming the *collective action space* into a multi-purpose *structural incentive space*.' (Centola and Heckathorn 2010:47-8). This possibility warrants close examination.

The rest of this section introduces the following topics: the payoff matrix; the production of a collective good; and, elite responsiveness and ideology.

The Payoff Matrix

The model provides trajectories of the level of collective good produced in the system and the relative frequencies of the strategies. The level is expressed as a proportion of full production. The payoff matrix determines the trajectories, given initial values and other constant parameters. There are three variables in the core payoff matrix: a value for the collective good (V), the net cost of contributing to collective action (K), and an exponent defining a production function (F). The state-space (Figure 8) is created by two dimensions, relative value (V/K) and the shape of the production function (F) (illustrated in Figure 7). Local and global value (V) and costs (K) are the same[24]; F is also constant in the example below but can vary, for example if a logistic production function is used. Local V is affected by the level of contribution (L), calculated on the basis of $L = 1 - (D/N)^F$, when D is the number of actors defecting and N is the total number of actors in the system. If interactions are pair-wise there are three possibilities; both cooperate, one cooperates and the other defects, and both defect[25]. Under those conditions D/N = 2/2, 1/2 or 0 respectively. That simplification is illustrated in Table 2.The two structural strategies carried by social roles are named here Defect and Contribute[26].

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23 We believe that Gilbert's version produces the frequencies of the Martinez Coll model but not the yields. We have revised his formulae as follows e.g. yieldd = Doves*rdd + Hawks*rdh + LawAbiders*rdl and yields = yieldd*Doves + yieldh*Hawks + yieldl*LawAbiders (cf. Gilbert and Troitzsch 2005:41)

24 Heckathorn addressed the question of unequal contributions in an earlier model.

25 A later model includes provision for a critical mass greater than two (Centola and Heckathorn 2010).

26 Heckathorn uses C to denote Cooperation. In general usage cooperation carries complex connotations that may or may not apply in specific cases. In this application there is no assumption that contributions are willing or motivated by a desire to co-operate.

Many, perhaps most, roles carry both strategies in some form or another. The interactions are regarded as voluntary at this point; sanctions are introduced at the next stage.

Table 2: Generic Payoff Matrix for the First-Level Game

	Contribute	**Defect**
Contribute	$R = V - K$	$S = V(1 - .5^F) - K$
Defect	$T = V(1 - .5^F)$	$P = 0$

(Heckathorn 1996:256)

The payoff matrix is a representation of social structure (refer to Figure 1). The generic form of the payoff matrix allows the cells to take any one of five logical sets of ordinal ranking. The theoretical basis of the model then creates what is in effect a phase diagram of ideological regimes (Heckathorn 1998) and can be used to generate a substantial set of hypotheses related to the response of elites, the shape of the production function, and the relative costs of coordination, information and sanctions. The cell labels T, R, P and S are used for all games even though the initials[27] are only directly applicable to the Prisoner's Dilemma. For example the ranking of cells in a Prisoner's Dilemma is T > R > P > S. Parameter values for V, K and F (see Figure 8 below) establish the ordinal ranking of the four cells. The five combinations of ordinal ranking of cells in First Level Games are each taken to represent a social dilemma created by tensions between individual and collective interests. For example if V/K = 1.4 and F < 0.4 the ordinal ranking of payoffs is R > T > P > S. This is an Assurance Game in which the most significant barrier to cooperation is obtaining an assurance that others will cooperate. The characteristic social dilemma in this region is coordination of contributors. A contrasting state exists when F > 1.8 at the same level of V/K. The ordinal ranking of payoffs is T > R > S > P, a Chicken Game. This is creates a pluralist, bargaining environment in which the social dilemma is finding the optimum balance between concession and conflict, or alternatively estimating the optimum level of resistance to exploitation.

The Causal Loop Diagram for the First Level Game is provided in Figure 6. The definition of variables and parameters has reached the second stage of Jacobsen and Bronsons' (1987) approach to defining sociological concepts as variables for system dynamics modelling, namely a general descriptive name and the use of relative frequency as a unit of measurement. Subsequent stages will address the other standards by being context specific, defining the semantic core and identifying observable practices.

[27] T: Temptation; R: Reward; P: Punishment; S: Sucker

Figure 6: A Causal Loop Diagram for the First Level of Heckathorn's 'Dilemmas and Dynamics' Model (the initial used for variables are taken from Table 2)

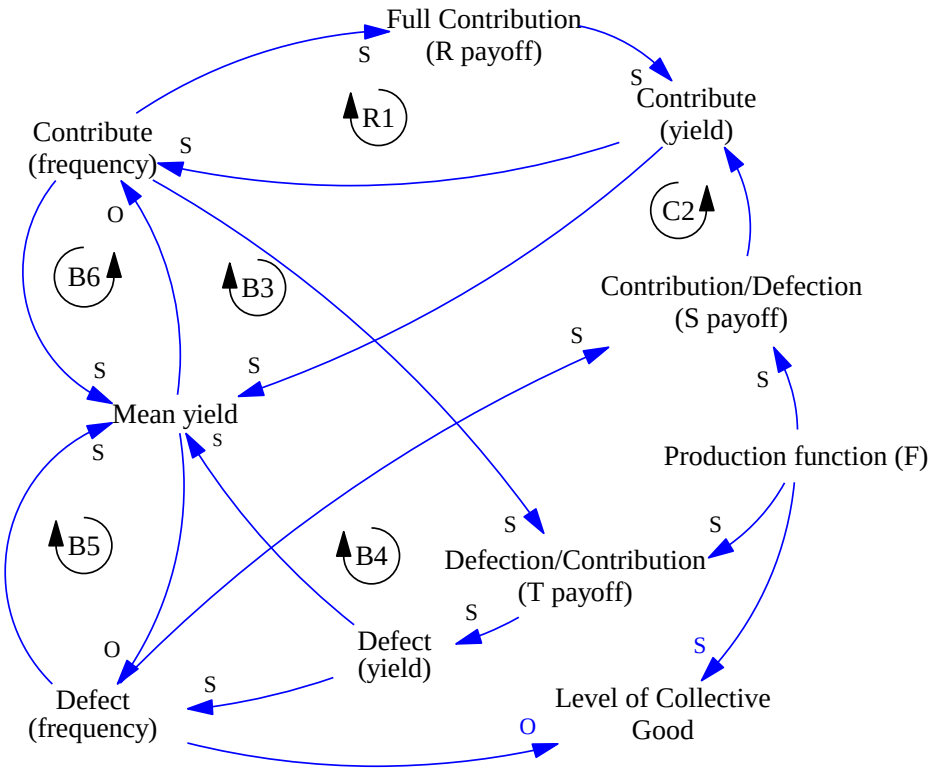


Table 3: Descriptions of Loops in Figure 6

Loops with up to 4 links	Description, assuming V > 0 and Full Defection P = 0
R1	If V > K, that is if R > 0, then the loop contributes to an increase in the frequency of strategies to Contribute
All other loops pass through Mean yield	
C2	The direction of the influence of Defection on C yield is contingent on the Production Function relative to V/K (see Figure 8)
B3	Equilibrium when: C yield = Mean yield, or C = 0
B4	As for C2 without costs consequently T is positive in all scenarios
B5 and B6	As for B3, equilibrium is reached if yields converge of mean yield or strategies are extinct

R: Reinforcing. C: Contingent. B: Balancing.

Production of a Collective Good

Heckathorn's discussion of collective goods refers to Mueller's definitions of public and semi-public goods (Heckathorn 1996:253). Mueller uses the example of 'a system of property rights and the procedures to enforce them [as a case of] a Samuelsonian public good in that "each individual's consumption leads to no subtraction from any other individual's consumption of that good". Alternatively, a pure public good can be defined as one that *must* [or later *may*] be provided in equal quantities to all members of the community.' (Mueller 2003:10&11) A norm of impartiality with

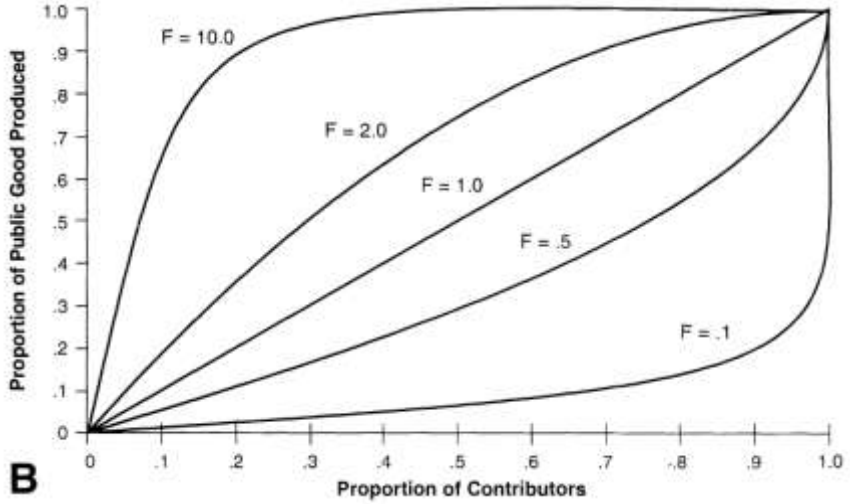
associated rights and duties seems comparable to a regime of property rights in the sense that it can be held to be a universal rule although initial values and selection processes stratify outcomes. Judicial impartiality provides an example of this (Black 2002)[28]. Consequently there are two processes to be considered. Firstly, direct defection from contributing to the public good which is included in the model. Secondly, the nature of a formal public good that at the margin is excludable, rivalrous and might incur increasing average costs (cf. Mueller 2003:11). The two gradients in Figure 4 will be examined more closely from these perspectives.

As stated above, the main output of the model is a trajectory of the Level (proportion) of Collective Good produced. The Level is determined by the proportion of contribution-defection in the population and the production function exponent (F). That is:

$$\text{Level of Collective Good} = 1 - (\text{The Proportion of the Population Defecting})^{F}$$

In the scenarios that follow the production function is constant as in Figure 7. Other functions can be used such as the logistic function that described the trajectory shown by the dotted line in Figure 8 which passes through all five regions in the State Space.

Figure 7: Production Functions Showing the Relationship between the Proportion of Contributors and Proportion of Public Good Produced

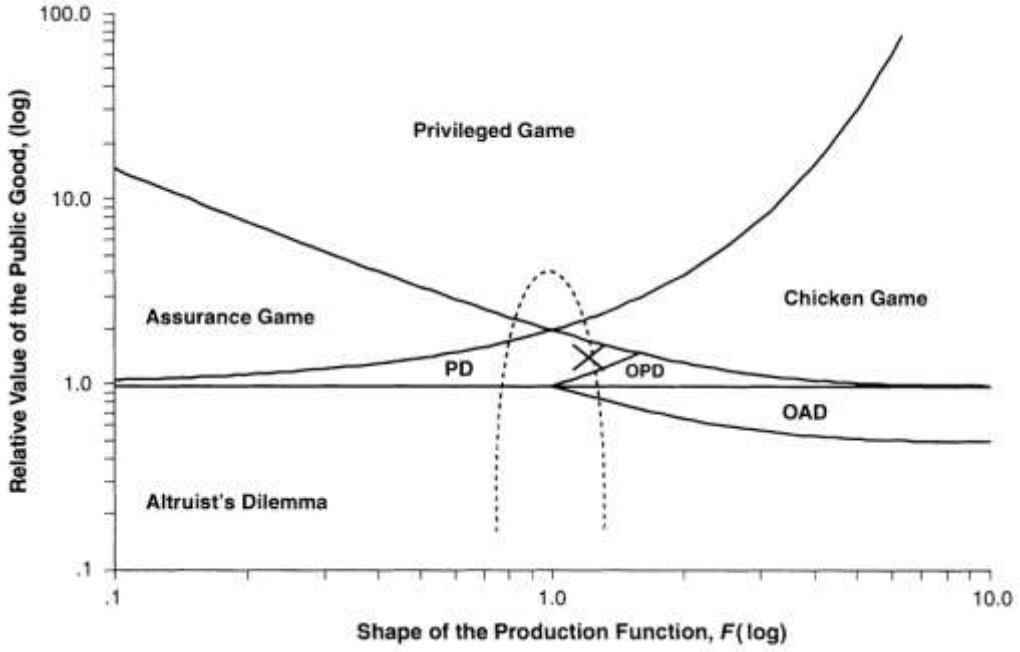


(Heckathorn 1996:252)

The five ordinal rankings of cells create the games shown in the social State Space in Figure 8. In this project interest is concentrated in the range $1 < V/K < 4$ where interaction produces net value but costs have an appreciable impact. Scenarios replicate Heckathorn's examples which are generally set at $V/K = 1.4$, which references to results of Hirschleifer and Martinez Coll.

[28] See also Fararo (2001).

Figure 8: Heckathorn's Game-Space Diagram Showing the Set of Games Generated by the Relationship between the Shape of the Production Function (F) and the Relative Value of the Public Good (V/K).



(Heckathorn 1996:257)

Elite Responsiveness and Ideology

The model is particularly interesting and applicable to governance because of associations between elite responsiveness, ideologies and the five primary games. In this application of the model F is used as a measure of elite responsiveness-repression (Centola and Heckathorn 2010:4)[29]. F<1 indicates a degree of resistance and a requirement for investment in organisation with the prospect of accelerating returns later in the process. F>1 is interpreted as a situation where elites respond early but contributors face continuously diminishing returns. Elite responses are directly related to the dominant ideology. Heckathorn suggests that ideologies emerge to simplify and address tensions among individual and collective priorities (Heckathorn 1998). In these terms the structural incentives in four of the five regions in Figure 8 generate characteristic dilemmas. The fifth region consists of interactions where mutual contribution is universally preferred – hence a 'privileged' game.

Heckathorn identifies primary ideologies that correspond to each region. Three examples are considered here; in combination there are 31 ideological sets[30]. The three ideologies are Authoritarianism (Assurance Game), Collectivism (Prisoner's Dilemma) and Pluralism (Chicken Game) (Heckathorn 1998:466). Each ideology implies different definitions of 'defect', 'contribute', 'collective good' and 'impartiality'. Take for example the dynamics of the Prisoner's Dilemma. In the short term, participants gain from defecting when others contribute, however if defection invades the system all lose the collective good. Following Sen's emphasis on freedom, a candidate norm might be derived from an ideology that asserts the freedom of one is contingent on the freedom of all, with a universal exchange of rights to constrain opportunism. This would be candidate for a norm of impartiality.

In the Assurance and Chicken Games defection indicates deviance or dominance respectively. Authoritarian ideologies address coordination problems by constraining disorder, deviance and dissent, with or without high levels of coercion. For example, there might a unified source of

[29] Other interpretations can be used e.g. the nature of the task (Heckathorn 1998:457)

[30] Others have explored this aspect of the model. Note in particular Ziegler on oscillations which, as noted above, are a feature of interest in this project.

'leadership' acting on the basis of 'common-sense'. This mode of organisation requires a high proportion of contributors to produce a significant level of collective good. Full production of the collective good indicates complete conformity. The Chicken Game simulates a bargaining dilemma including the problem of optimising resistance having regard to costs of concession and conflict. Ideological responses to bargaining focus on issues of equity and exploitation. Full production of the collective good indicates that conflict has been optimised after an early and complete response.

Voluntary Interaction

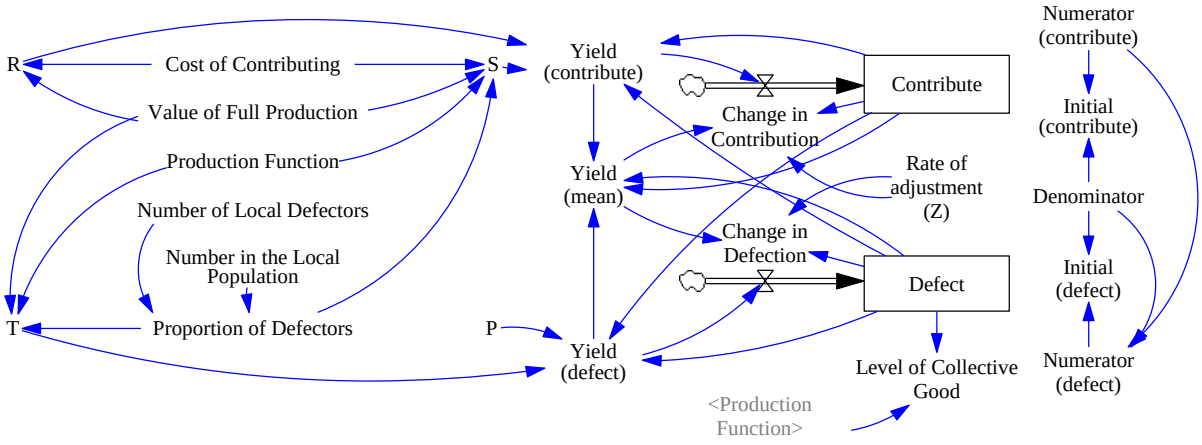
This section introduces the output of the model with two scenarios that contrast the level of collective good produced by voluntary action in unregulated and bargaining environments. In all scenarios V (Value) = 1.4 and the Rate of adjustment (Z) = 0.05. The Rate of adjustment simulates the extent of change at each iteration, interpreted as effective selection pressure. The other parameters are varied as shown in Tables 4 and 6.

Table 4: Scenarios illustrating dynamics across selected thresholds

Scenario No.	Initial Value			Elite responsiveness (F)	Costs	
	Contribute	Defect	TFT		K	K_{Inf}
1	1/2	1/2	0	1.22	1	0
2	1/2	1/2	0	4.8	1	0

The First Level model has the following Stock-Flow Diagram:

Figure 9: Stock-Flow Diagram for the First Level Model

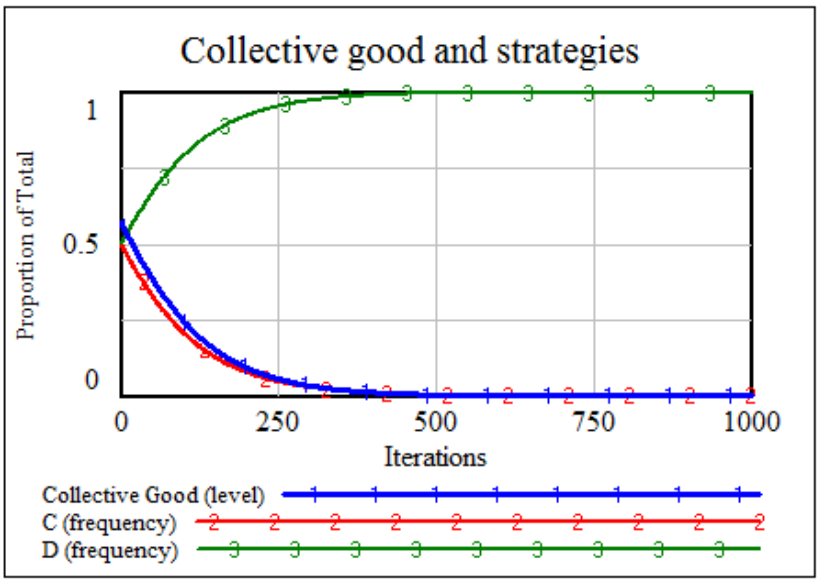


One stock is redundant. It has been included because it is relevant when the number of strategies is increased. P = 0 and similarly has been included to depict the logic in the model. There is further description of this model in the Appendix.

The first scenario (Figure 10) is the standard Prisoner's Dilemma in which there are no sanctions and payoffs provide incentives for opportunism. F = 1.22 replicates values used in the studies cited above. As is frequently noted, the logic of this structure selects a sub-optimal state of complete defection and

no collective good. Possible responses include regulation, an exchange of rights so each relinquishes control of their own strategy but gains control of others, or, in the OPD (Ordinal Prisoner's Dilemma) zone of Figure 8, alternates between Contribute and Defect. This dynamic can be observed when constitutional rights are unresolved and manoeuvring on those issues prevents concerted action on substantive issues. It is evident when claims are made by representatives of populations with adverse health outcomes who not sufficiently organised to create a bargaining environment.

Figure 10: Opportunism and Voluntary Interaction (Scenario 1)

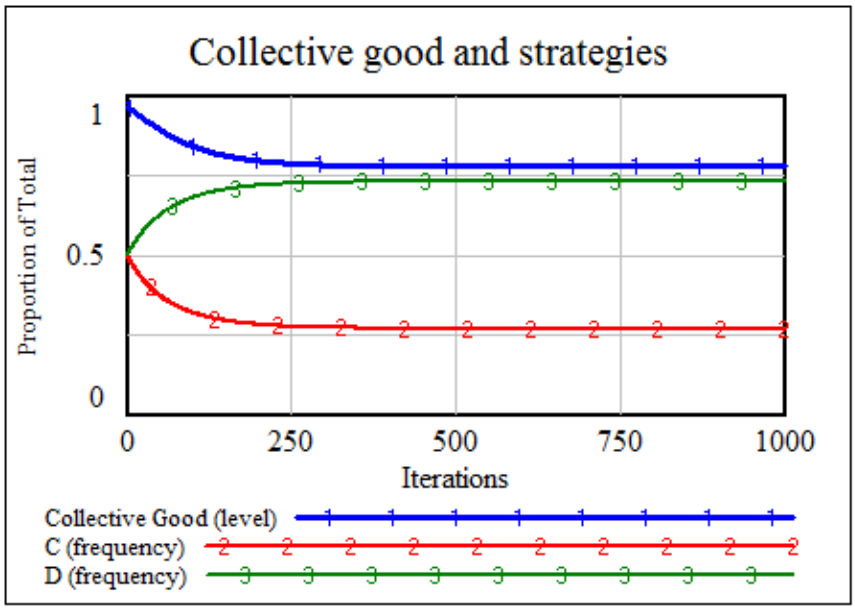


[V = 1.4; K = 1; F = 1.22][31]

In a bargaining environment there is a positive return on compliance (Contribute-Defect), consequently a mix of Defection and Contribution is viable. In that setting, the level of collective good rises relatively rapidly as F increases. Figure 11 might approximate a structure consistent with the distribution in Figure 4.

[31] The outputs generally replicate those published by Heckathorn (1996) except that initial levels of collective good are about 0.05 greater than in Heckathorn's results.

Figure 11: Exploitation and Voluntary Interaction (Scenario 2)



[V = 1.4; K = 1; F = 4.8]

A Second Level Strategy

This section begins to demonstrate how the model can be extended by adding a 'Tit for Tat' (TfT) strategy to introduce constraints inherent in reciprocity. The full model has a seven by seven matrix that includes selective sanctioning by two competing normative regimes (Heckathorn 1996:262). The next step is shown in Table 5.

Table 5: Payoff Matrix including the Tit For Tat strategy

Strategy	**Contribute**	**Defect**	**TfT**
Contribute	R	S	R
Defect	T	P	P
TfT	$R - K_{Inf}$	$P - K_{Inf}$	$R - K_{Inf}$

(Heckathorn 1996:262)

The new variable (K_{Inf}) recognises costs of complexity, including information costs, implied by a reactive strategy. The stock-flow diagram in Figure 12 repeats the First Level model in Figure 9 and adds an additional module to represent the third strategy. Again one stock is redundant until others are added.

Figure 12: Stock-Flow Diagram extended to incorporate TFT

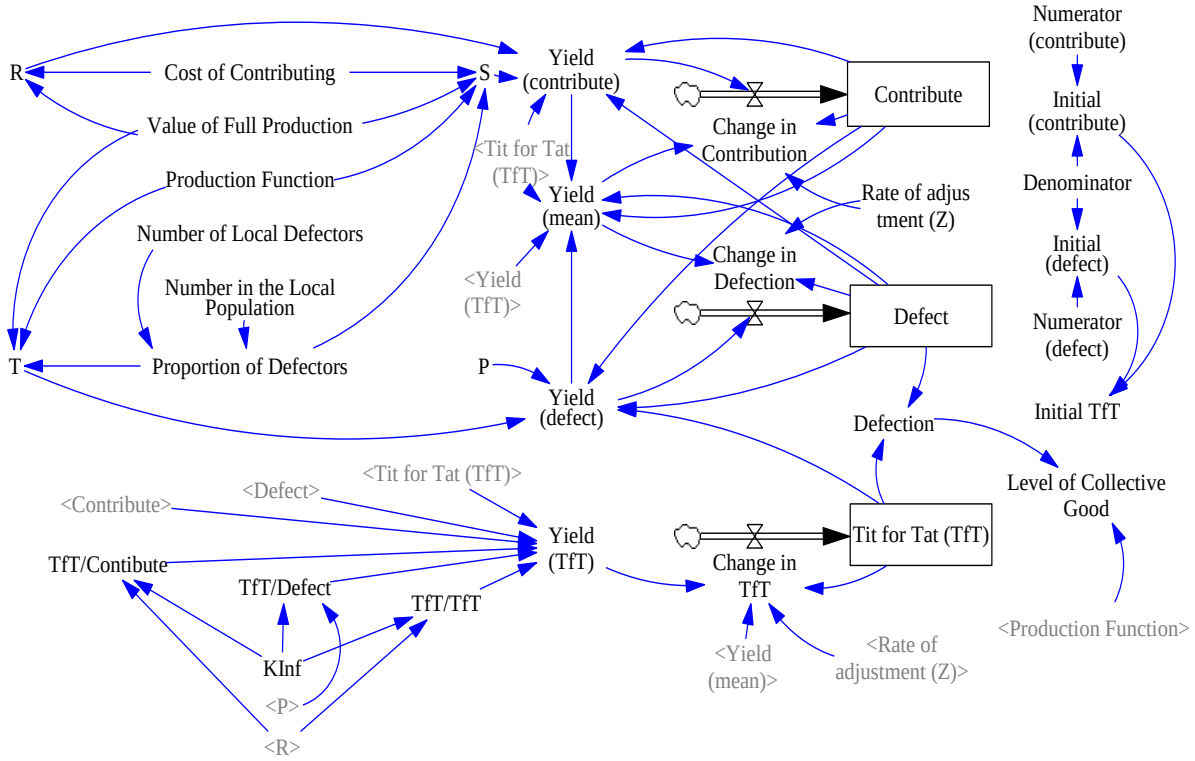
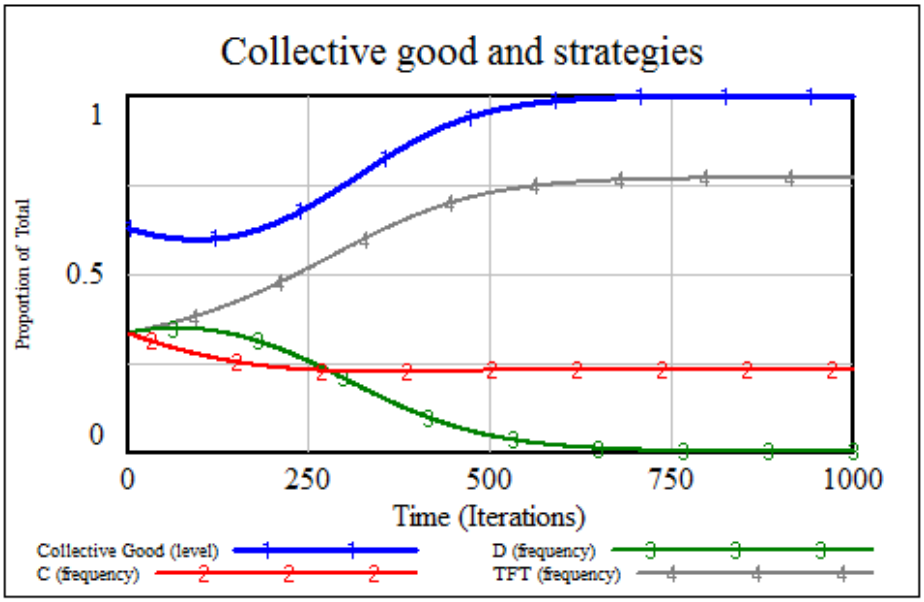


Table 6: Scenarios illustrating dynamics across selected thresholds

Scenario No.	Initial Value			Elite responsiveness (F)	Costs	
	Contribute	Defect	TFT		K	K_{Inf}
3	$^1/_3$	$^1/_3$	$^1/_3$	1.22	1	0
4	$^1/_{10}$	$^9/_{20}$	$^9/_{20}$	1.22	1	0.1
5	$^1/_3$	$^1/_3$	$^1/_3$	3.0	1	0

Two additional thresholds can be identified. These hypotheses are of practical interest. There is a set of health promotion initiatives that rely on principles of reciprocity and exchange, sometimes associated with community development based on local partnerships, networks and resources (e.g. Cody 1999:54). This thinking was influenced by the academic currency given to reciprocity as a 'winning strategy' (Heckathorn 1996:266-7). The model points to the significance of relatively small changes in relative cost as explanations of why strategies succeeded and failed. In Figure 13 TfT extinguishes defection and maintains voluntary contribution in a Prisoner's Dilemma. The cost of complexity or information is relatively low, such as might be the case in relatively small local groups with no corporate membership.

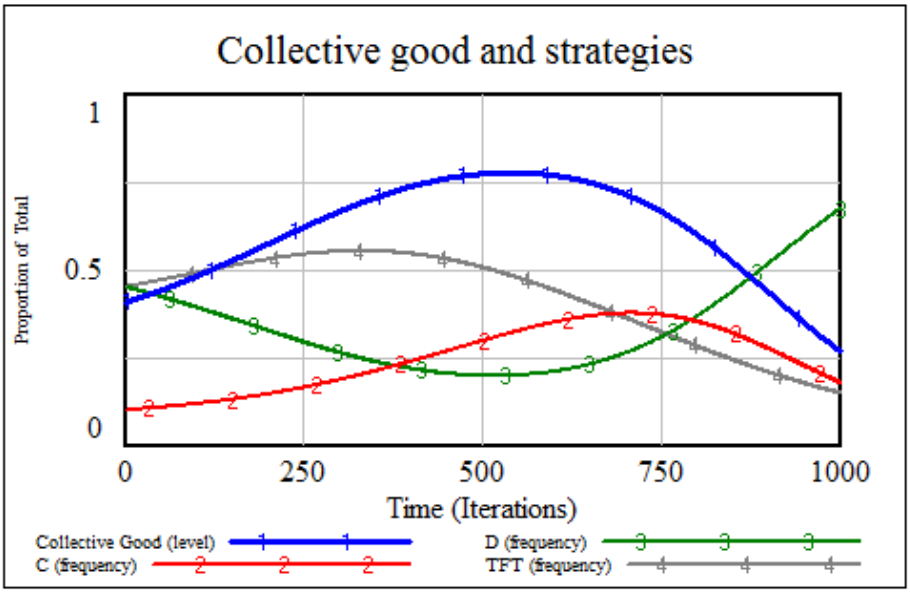
Figure 13: Opportunism and Reciprocity (Scenario 3)



[V = 1.4; K = 1; F = 1.22; K_{Inf} = 0]

However TfT is not robust in some settings. One is when there are appreciable costs of circulating information or dealing with complexity, the other is in a bargaining environment. In the range 0.01 < K < 0.04 the Level of Public Good fluctuates and at higher costs it is unsustainable. However if the initial frequency of TfT is relatively high and equivalent to strategies that Defect the early trends are misleading (Figure 14). This is similar to the trajectory observed in community-based projects reported in an earlier paper (Cody, Cavana et al. 2007).

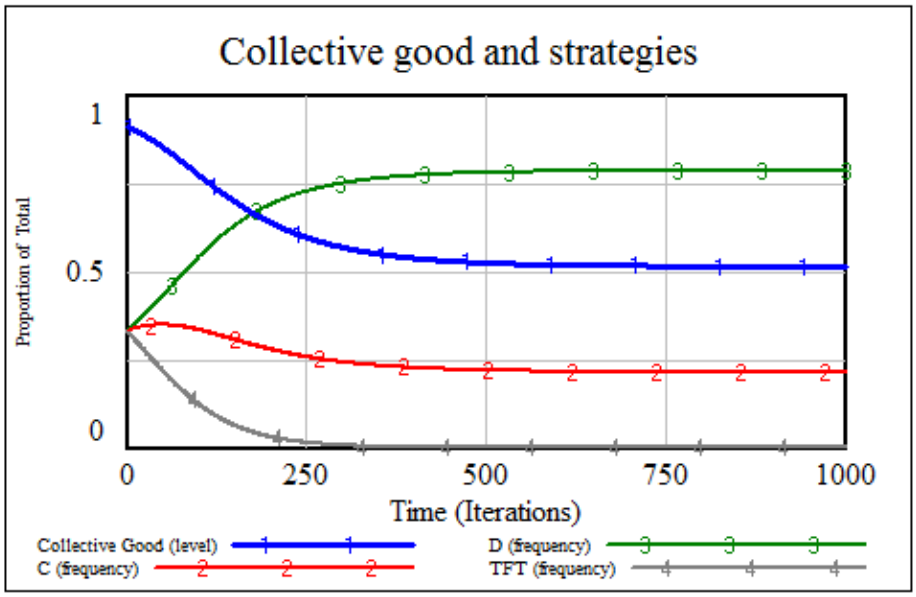
Figure 14: Opportunism and Reciprocity with relatively small, costs of complexity (Scenario 4)



[V = 1.4; K = 1; F = 1.22; K_{Inf} = 0.1 Note: in this scenario the initial values are not equal]

Even if there are no costs associated with the TFT strategy it does not survive in a bargaining environment (Figure 15). This is interpreted as a shift from a regime characterised by exchange of rights to one that balances concessions to optimise conflict.

Figure 15: Exploitation and Reciprocity (Scenario 5)



[V = 1.4; K = 1; F = 3; K_{Inf} = 0]

These thresholds seem important. In the context of this discussion they point to constraints when replicating direct, interpersonal relations in institutional settings.

The principles used to construct the model to this point can be extended considerably. Mention has been made of trajectories created by logistic production functions and adding sanctioning strategies of opposing normative regimes. Ziegler (1997) has used the model to study oscillations of asymmetric games. Heckathorn and Centola have produced a revised version of the model that addresses other issues related to the mobilisation of social movements such as the critical mass in local coalitions, increases in coalition size, a distribution of local value and the significance of affinity (homophily) (Centola and Heckathorn 2010).

Conclusions

Two provisional conclusions are proposed here. Firstly, it seems Heckathorn has devised a model that meets some of the most important modelling standards of the System Dynamics community. The model is: a formal statement of general hypotheses applicable to a domain; suitable for tailoring to specific situations by parameterisation; and a template for meaningful experimentation with generalised case studies (Lane and Smart 1996:102). The model provides strong hypotheses that predict the policy framework that will be used in various contexts, draws attention to some sources of resistance, and generates alternatives, such as game changing that might reveal implications for resistance and conflict. In that sense the model assists the user identify options and distinguish those options from past practice (Forrester 2007:365-6). Further, it is a compact, generic model that classifies systems in a way that accounts for dynamics and provides useful guidance when searching for empirical evidence in a mass of data. For these reasons Heckathorn's 'Dynamics and Dilemmas of Collective Action' model might be considered a template for contributions to a 'library' of canonical situation models (Lane and Smart 1996:102).

Secondly, with respect to the substantive issue of stratification of roles and the consequent profiles of effort, stress and risk encountered by natural persons, the model generates scenarios using a

parsimonious representation of voluntary interactions and sanctioning in the context of five basic dominant ideologies. This provides a useful point of entry to a logical set of interpretations of 'disparity' and for identifying contexts in which health disparity can be regarded, and perhaps authoritatively recognised, as a public issue. If it can be assumed that the relevant collective good reduces social disparities related to determinants of health, then the scenarios estimate the extent to which net social pressures will maintain health disparities. The validity of the estimates can be tested empirically using indicators of social constraint

Appendix: The generic variables used in the Stock-Flow Diagram (Figure 9)

Names; (Initials)	Type	Description	Unit of measurement
Contribute (frequency)	Level	Strategies (or sets of practices) that contribute to the collective good. It is assumed that all contributions are equal.	Relative frequency
Defect (frequency)	Level	Strategies (or sets of practices) that defect from contributing to the collective good.	Relative frequency
Change in Contribution	Rate	Response to selection pressures in the payoff matrix	Relative frequency/period
Change in Defection	Rate	Response to selection pressure in the payoff matrix	Relative frequency/period
Value of Full Production; Value (V)	Constant	The value of full production of the collective good	Proportion of full value produced
Cost of Contributing; Cost (K)	Constant	The average marginal cost of producing the collective good. The marginal cost is 0 if there is pure jointness of supply.	An arbitrary scale from 0 to any positive number
Production function exponent (F)	Constant	The exponent controlling the shape of the function that links contribution to the level of collective good produced.	Input: Proportion of contribution Output: Proportion of collective good produced
Rate of change (Z)	Constant	The rate at which the selection pressures in the payoff matrix influence the relative frequency of strategies	Proportional rate of adjustment to equilibrium
Number of Local Defectors	Constant	The proportion of local coalitions that defect when there is partial contribution.	Number, set at 1 in the basic model
Number in the Local Population	Constant	The size of local coalitions	Number, set at 2 in the basic model
Level of Collective Good (L)	Auxiliary	The proportion of collective good produced relative to production at full contribution	Proportion of full production, 0 – 1
Contribute (yield); C yield	Auxiliary	Sum of the payoffs for each element of the strategy multiplied by the frequency of the other strategy	Relative fitness
Defect (yield); D yield	Auxiliary	Sum of the payoffs for each element of the strategy multiplied by the frequency of the other strategy	Relative fitness

Mean yield	Auxiliary	Sum of the yields for each strategy multiplied by the frequency of the relevant strategy	The weighted average of the relative fitness of all strategies
T, R, S and P (see Table 2)	Auxiliary	The payoff from each type of interaction	Relative payoff referenced at P = 0
Proportion of Defectors	Auxiliary	The number of local defectors divided by the number in the local population	Ratio

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