Chapter 1
Human Development Dynamics: Network Emergence in an Agent Based Simulation of Adaptive Heterogeneous Games and Social Systems

Mark Abdollahian, Zining Yang, Patrick deWerk Neal, and James Kaplan

Abstract In the context of political modernization and economic development, the complex adaptive systems framework can help address the coupling of macro social constraint and opportunity with individual agency. Using a simple evolutionary game approach, we fuse endogenously derived socio-economic system dynamics from Human Development (HD) Theory with Prisoner's Dilemma spatial intra-societal economic transactions. We then explore a new human development dynamics (HDD) model behavior via quasi-global simulation methods to explore technological progression on economic development, cultural plasticity, social and political change. Using network analysis, we then investigate the impact of technology proliferation on communications ease and the resulting compression of social space on individual wealth and political preference formation. As economic and social capital is created, past transaction histories tend to reinforce future success, and networks emerge and solidify at different rates depending on technology. Increasing social connectivity in small populations has an immediate and positive impact on wealth creation, yet those effects become negative as technology proliferates and population size increases. This suggests not only diminishing marginal returns to increasing communications' payoffs to individuals but moreover crowding out effects. We believe complex adaptive or evolutionary systems approaches are necessary to understand both near and potentially catastrophic, far-from-equilibrium behavior and societal outcomes across all human scales of modernization.

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1 Introduction

Rooted in comparative political economy, the HD perspective is a qualitative, transdisciplinary approach to understanding modernization and development through the lens of interdependent economic, cultural, social and political forces across individual, institutional and societal scales. Here we extend Abdollahian et al.'s (2012, 2013, 2014) novel, quantitative systems dynamic representation of HD theory at the societal level towards integrated macro-micro scales in an agent based framework. Quek et al. (2009) also design an interactive macro-micro agent based framework, which they call a spatial Evolutionary Multi-Agent Social Network (EMAS), on the dynamics of civil violence. In this paper, we focus on how advances in technology, proxied by increasing or decreasing potential agent interactions by varying network effects identified by Abdollahian and Yang (2013; Yang and Abdollahian 2014) impacts individual wealth creation and ultimately societal development paths.

In order to create a robust techno-social simulation (Solow 1956; Vespignani 2009), we instantiate a system of asymmetric, coupled nonlinear difference equations that are then empirically validated with five waves of data from the World Values Survey (2009). We then fuse this system to agent attribute changes with a generalizable, non-cooperative Prisoner's Dilemma game following Axelrod (1987, 1997a, b) and Nowak and Sigmund (1993, 1998; McPherson et al. 2001; Moyano and Sanchez 2013) to simulate intra-societal, spatial economic transactions where agents are capable of Robust Adaptive Planning (RAP). Here we specifically focus on the spatial network effects from various network sizes of heterogeneous agent interactions. Understanding macro-socio dynamics and individual agency across different sizes of emergent intra-societal transaction networks are key elements of a complex adaptive systems (CAS) approach.

Our technology proliferation results indicate that increasing agent Degree centrality in expanding communications networks drives strong individual wealth creation albeit up to a limit where competition from other agents creates a crowding effect. Similar results are obtained as Closeness centrality differs with varying communication network size, suggesting tipping points where individuals and societies can maximize wealth creation and hints towards macroeconomic conditional convergence. Overall we find strong epistatic interactions, where either social or financial networks and strategies are interdependent similar to Oh (2009), Uzzi (1996, 1999) and Zhou et al. (2003). Local social co-evolution of communication networks (Gurr 1970) help determine individual-micro and global-macro development outcomes in a particular society.

2 HD Dynamics Background

HD postulates a complex modernization process where value orientations drive an individual's level of existential security and change in predictable ways given shifts in existential security. HD theory provides a framework in which economic development, societal wealth and human needs create generalizable shifts in cultural predispositions and political behavior (Griffin 2009; Gurr 1970; Inglehart 1997; Swan 1956; Inglehart and Welzel 2005). HD theory expands upon economic drivers from neoclassical growth theory (Solow 1956; Swan 1956; Barro 1991) commonly attributed to high growth paths and convergence (Acemoglu and Robinson 2012, Axelrod 1997a). Such approaches specify detailed and interactive vectors of economic determinants, country and time-specific effects separately (Binmore 1994; Caselli et al. 1996); HD theory fuses cultural, social and political development process into economic growth (Y) dynamics.

Rational-secular (RS) *cultural* values correspond to individuals' growing emphasis on technical, mechanical, rational, and bureaucratic views of the world. During economic industrialization phases, cultural dispositions tend to progress from an emphasis on traditional pre-industrial values—often measured in terms of religious ceremony attendance—to secular world views, transferring authority from traditional religious figures to technological progress and bureaucratic political life.

Self-expressive (SE) *social* values corresponds to the post-industrial phase of economic development where the wealth and advanced welfare system generated by education, increased productivity and service-related economic activities provides individuals with an overwhelming sense of existential security (Barro 1991; Bell 1973) and the freedom to seek self-expression and demand political participation. Self-expression values promote liberal political institutions through two mechanisms. First, to the extent that there is incongruence between cultural demand for, and political supply of, liberal institutions, individuals are more or less prone to elite-challenging activity (Feng 2003; Darity 2008; Eckstein and Gurr 1975; Gurr 1970). Second, self-expression values support the social acceptance of basic democratic norms such as trust and political participation. The end result is a gradual transition toward democratization in autocratic nations and more effective political representation in democratic nations (Inglehart 1997; Inglehart and Welzel 2005).

Lastly, HD theory expects democratic (D) *political* values to exhibit positive feedbacks with economic progress, based on previous work on liberal institutions and economic development (Caselli et al. 1996; Bell 1973; Diamond 1992; Abdollahian et al. 2013; Acemoglu and Robinson 2012; Boix and Stoke 2003; Diamond 1992; Feng 2003). Declining economic conditions reintroduce the primacy of basic needs, fueling conditions for more traditional value orientations and less self-expression. Disequilibrium between culturally defined political expectations and political realities promotes and provides motivation for revolutionary change.

The HD perspective suggests a staged process in which rising level of existential security via economic development leads to an increased emphasis on rational-secular and self-expression values. However, these effects are neither linear nor monotonic, as we see strong reversion towards autocratic institutional preferences in

survival-minded societies. Democratic norms and institutions that outpace economic progress are inherently unstable with a persistent, turbulent reversion processes, even at high levels of democratic norms and existential security. This suggests that societies experiencing democratization can frequently expect punctuated reversals and revolutions towards more autocratic institutions until more sustainable economic growth and democratic institutions re-emerge.

3 A Human Development Dynamics Model

While innovative and the first to formalize a systems approach for HD theory, a limitation of Abdollahian et al.'s (2012) work is the lack of coupling and interdependence across human scales, from individuals to institutions and finally the societal outcomes they generate. Our HDD model uniquely combines the interactive effects and feedbacks between individual human agency as well as the macro environmental constraints and opportunities that change over time for any given society. Decisions by individuals are affected by other individuals, social context, and system states. These decisions have variegated first and second order effects, given any particular system state or individual attributes. Such an approach attempts to increase both theoretical and empirical verisimilitude for some key elements of complexity processes—emergence, connectivity, interdependence and feedback—found throughout several disciplines across all scales of modernization and human development.

We maintain individual agent attribute relationships and postulated changes of *RS*, *SE*, *D* and *Y* in keeping with HD theory. These endogenously derived, individual agent attributes (RS^i, SE^i, D^i and Y^i) impact how economic transaction games occur, either increasing or decreasing individual wealth and, at increasing scales, determining societal productivity (Barro 1991; Binmore 1994). Geography and proximity are allowed to play a role by instantiating in random two-dimensional lattice worlds.

Capturing individual agent endogenous processes, we first transform Abdollahian et al.'s system of equations from differential to discrete equations for NetLogo tractability and use their empirically validated parameter values as a good first approximation. Given individual citizen attributes and HD processes at each iteration, we sum up each agent attributes across Y, RS, SE and D to find resulting societal distributions for each variable, yet are mindful of ecological correlation. This allows us to explore the interactive effects of income inequality, cultural schisms, social complexity or highly polarized political dialogues in any given society as the emergence of individual efforts and patterns of interactions (Fig. 1.1).

Social co-evolutionary systems allow each individual to either influence or be influenced by all other individuals as well as macro society (Sala-i-Martin 1996; Welzel et al. 2003; Snijders et al. 2007; Zheleva et al. 2009), perhaps eventually becoming coupled and quasi-path interdependent. Accordingly, we instantiate non-cooperative, socio-economic Prisoner's Dilemma (PD) transaction games given the similarity of agent *i*'s attribute vector (A^i) of social, cultural, political and economic preference (RS^i, SE^i, D^i and Y^i) to agent *j*'s attribute vector (A^j) for selected

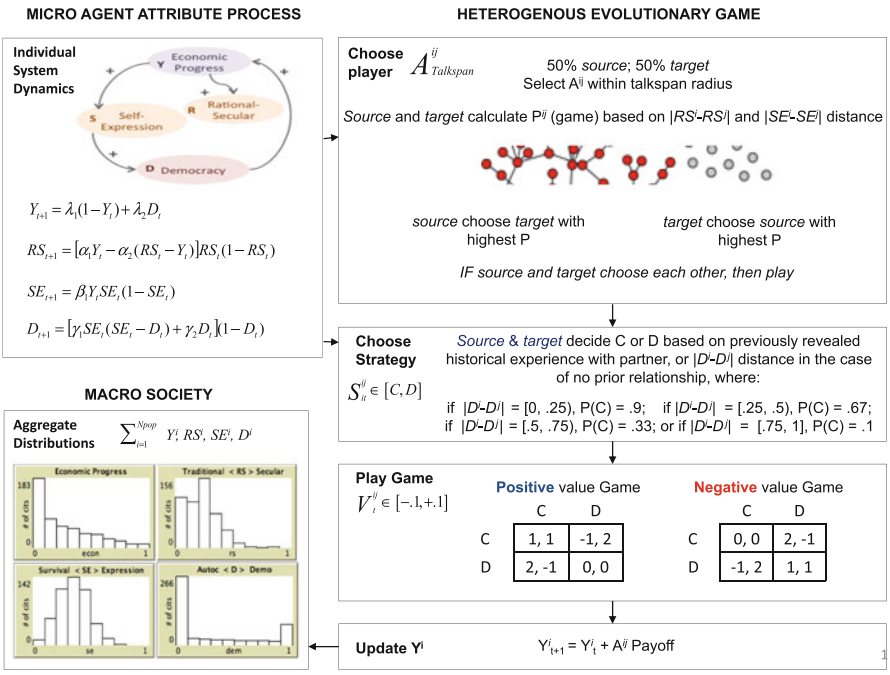

Fig. 1.1 HDD architecture (Implemented in NetLogo (Wilensky 1999))

A^{ij} pairs. Here, symmetric preference rankings and asymmetric neighborhood proximity distributions allows "talk-span," a Euclidean radius measure, to proxy for communications reach, social connectivity and technology diffusion constraining the potential set of A^{ij} game pairs. Low talk-span values restrict games to local neighborhoods among spatially proximate agents, while higher talk-span values expand potential A^{ij} pairs globally, modeling socially compressed space.

Following Social Judgment Theory, the attribute positions of two agents are conceived as a Downsian continuum (Boix and Stoke 2003; Eckstein and Gurr 1975; Darity 2008; Griffin 2009) where distance between these positions symmetrically affects the likelihood of one accepting the other's position. Agent i evaluates the likelihood of conducting a transaction with agent j based on similarity of socio-cultural preferences $|RS^i - RS^j|$ and $|SE^i - SE^j|$ within the given neighborhood. This captures communications and technology diffusion for frequency and social tie formation (Kauffman 1993; McPherson et al. 2001).

After transaction counterparties are identified, similarity is measured against an exogenous threshold to gauge compatibility. If both parties are satisfied, compatible agents, endowed with RAP cognition, enter into an engagement and search their memory for prior transactions with their period t counterparty. In the case of no prior transaction experience, agents individually each select strategy $S^{ij}{}_{it} \in$ [*Cooperate, Defect*] probabilistically based on similarity of political preferences as expressed by $|D^i - D^j|$ (Quek et al. 2009; Siero and Doosje 1993).

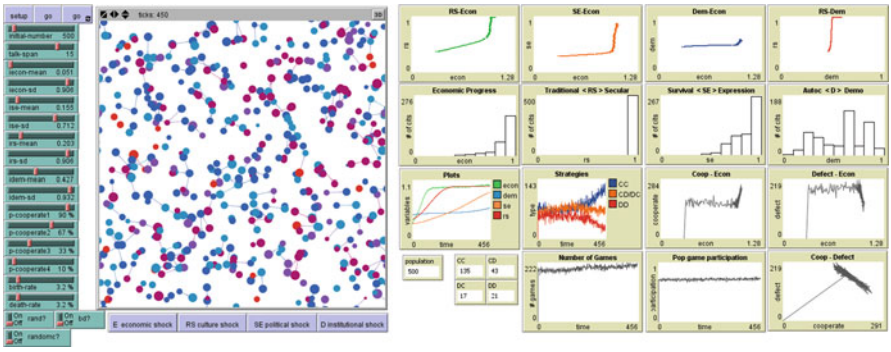

Fig. 1.2 Sample HDD run (*Source*: Abdollahian et al. 2013)

In repeat transactions, agents have perfect memory of *t-n* and will predicate their strategy in period t transactions on their counterparties' $t-1$ behavior such that $S^{ij}{}_{it} = S^{ji}{}_{j(t-1)}$. Agents are unaware of counterparties' strategy rule at any point in time. This can lead to the emergence of stable productive relationships, bad relationships featuring pure defection strategies over repeated interactions, and tit-for-tat relationships, where agents alternate between strategies and never sync into a stable productive transactional relationship. This reflects recent work on the affects on co-evolution of both dynamic strategies and updating rules based on agent attributes (Inglehart and Baker 2000; Mankiw et al. 1992; Kauffman 1993; Moyano and Sanchez 2013).

Following Nowak and Sigmund (McPherson et al. 2001), we randomly assign game transaction values. However, we do not asymmetrically constrain such values; any particular game transaction value between pairs, V^{ij}, lies in between [−.1, .1]. This instantiation allows for different potential deal sizes, costs, or benefits. We specifically model socio-economic transaction games as producing either positive or negative values as we want to capture behavioral outcomes from games with both upside gains or downside losses.

In our HDD framework, A_i strategies are adaptive, which affect A_{ij} pairs locally within a proximate radius as first order effects. Other agents, within the system but outside the talk-span radius, are impacted through cascading higher orders. Agents simultaneously co-evolve as strategy pair outcomes CC, DC/CD or DD at t affect Y^i at $t+1$, thus driving both positive and negative *RS, SE* and *D* feedback process through $t+n$ iterations. These shape A^i attributes which spur adaptation to a changing environment, summing Y^i, RS^i, SE^i and D^i vector values. Feedback into subsequent A^{ij} game selection networks and strategy choice yields a CAS representation across multiple scales (Fig. 1.2).

Before turning to our overall sensitivity and network results, we detail a single notional run. Here a lesser developed society, with a mean low income level but high degree of inequality, escapes the poverty trap through high growth and increasingly moderating democratic institutions. Individual productivity and wealth, driven by successful CC and DC/CD strategy outcomes of individual transactions,

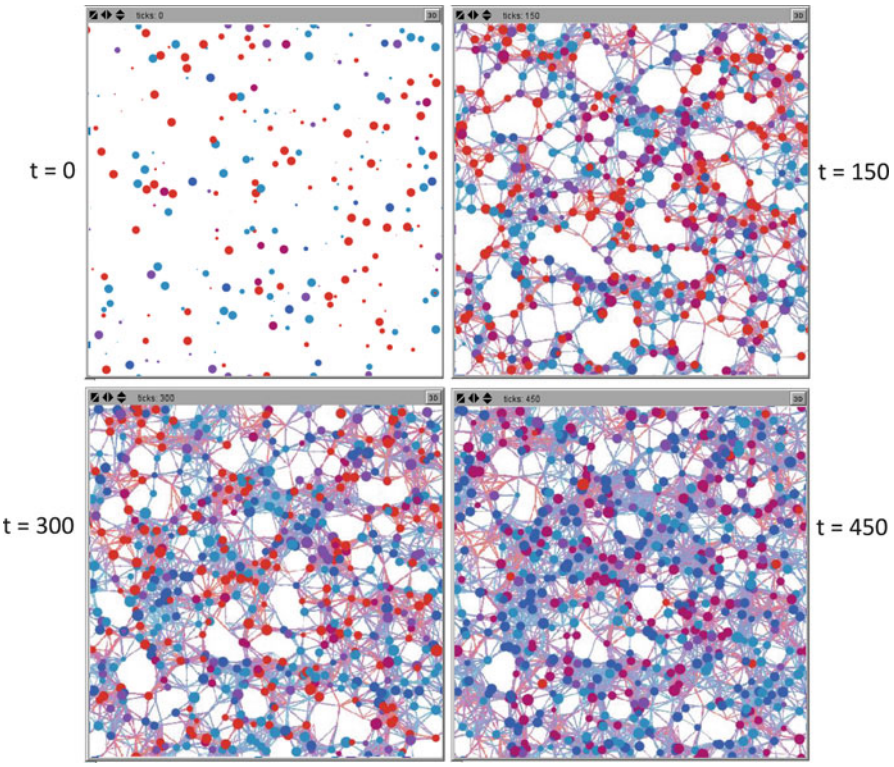

Fig. 1.3 Spatial network outcomes at t = 0, 150, 300, and 450

help accelerate the emergence of modern secular RS and expressive SE norms and values, while democratic D preferences solidify, but are not engrained throughout all of society. Figure 1.3 depicts spatialdistribution of agent wealth, preferences and the resulting communication networks from the above simulation at $t = 0$, 150, 300 and 450 snapshots. Initially, we find our low developed society with high-income inequality and polarization along autocratic and democratic preferences with no transaction networks. By $t = 150$, agents quickly increase in individual wealth as several economic transaction games are played between individuals of similar R and S preferences as shown by the emergent networks, while the strategy history shows not one dominant strategy emerges as society goes through a high growth phase of development. By $t = 300$, we see continued heterogeneously mixed populations in terms of income and democratic preferences with previously established network ties solidifying, while by $t = 400$ we see increased convergence toward democratic preferences and dense network clustering. Our resulting network structures are consistent with Gargiulo and Benassi's (2000) findings on how social capital flows impact network cohesion. Although just one particular simulation, what is critical is that co-evolutionary behavior results in path dependence of economic and cultural

change networks as well as being a key determinant for development outcomes. Moreover, changes towards democratic values leads to increasing cooperative strategy pairs, which reinforce previous network connections over time.

4 Sensitivity Analysis

In order to make more generalizable model inferences, Table 1.1 detailsthe interactive parameter effects[1] on economic prosperity *Y*, as well as strategy choice pairs CC, CD/DC and DD. As all variables are relatively scaled, we can interpret

Table 1.1 Impact on economic development and strategy pairs

Model	Economic	CC	CD	DD
Economic		1.099*	0.666*	0.498*
		(0.000)	(0.000)	(0.000)
Rational secular	0.492*	−0.354*	−0.186*	−0.137*
	(0.000)	(0.000)	(0.000)	(0.000)
Self expression	−0.128*	0.156*	0.071*	0.411*
	(0.000)	(0.000)	(0.000)	(0.000)
Democracy	0.262*	0.028*	−0.209*	−0.392*
	(0.000)	(0.000)	(0.000)	(0.000)
Cooperate	0.354*			
	(0.000)			
Defect	−0.080*			
	(0.000)			
Talk-span	0.255*	−0.199*	−0.051*	−0.068*
	(0.000)	(0.000)	(0.000)	(0.000)
Time	−0.111*	−0.176*	−0.065*	−0.334*
	(0.000)	(0.000)	(0.000)	(0.000)
Threshold	−0.063*	−0.204*	−0.318*	−0.365*
	(0.000)	(0.000)	(0.000)	(0.000)
RAP	0.024*	−0.020*	−0.289*	−0.135*
	(0.000)	(0.000)	(0.000)	(0.000)
N	78,591	81,982	73,499	61,877
Prob > F	0.000	0.000	0.000	0.000
R-squared	0.946	0.809	0.472	0.412
Root MSE	0.041	0.795	0.978	0.877

Numbers in parentheses are corresponding robust standard errors
*Significance at 1 \% level

[1]Parameter setting: talk-span = 0, 1, 4, 7, 10; threshold = 0, 0.04, 0.09, 0.16, 0.25, 0.36; RAP = true, false.

magnitude and substantive effects across OLS β coefficients. The results reflect a limited, quasi-global sensitivity analysis with 500 agents in 180 runs and 700 iterations in each run, randomly down-sampled for pooled OLS tractability.

Our first model on mean societal economic development *Y* confirms HD theory that positive values of mean societal *RS* and *D* values significantly speed the pace of economic development, although *SE* is significant and slightly negative; this may relate to a loss of productivity when efforts in isolation are directed away from production and towards self-expression. Looking at the impact of evolutionary games, we see that cooperation has a stronger positive impact than defection or mixed strategies in increasing transaction value to society. Time is slightly negative, indicating that economic prosperity is not endogenous to the model. Threshold, agent willingness to engage in transactions, is slightly negative, implying that reduced trust has a slightly negative impact on growth. Lastly, RAP is slightly positive, suggesting increased cognition is beneficial in our simulated environment. Future research will investigate to what extent the RAP coefficient increases with agent analytical sophistication, and may include an endogenous education component. Talk-span spatial proximity and network creation is positive and significant, confirming priors that increasing technology and compressing potential social space also speed development processes. Next we explore in detail network formation and their potential nonlinear effects.

5 Network Effects

In order to understand the emergence of transactional clusters, we explore the impact of technology proliferation and social compression through varying communication network sizes on individual wealth creation. Running a set of experiments, simulations were conducted with talk span set exogenously and identically for the entire agent population, in environments with different numbers of agents. For populations of 100, 200, 300, 400, 500 and 600 agents, 44 simulations were run for low to high talkspan values (between 1 and 20), for a total of approximately 5,200 simulations with identical starting conditions run for 500 ticks. A cumulative transaction graph then was generated during the course of each simulation, with edges representing historical PD transactions between agents. After each simulation, node level statistics $\text{Degree}_{i,t}$, $\text{Closeness}_{i,t}$ and economic wealth *Y* for each agent *i* at each tick *t* were extracted. Combining the PD transaction history with node level statistics allowed fixed effects panel regressions on how technology proliferation and network characteristics affect individual economic outcomes.

Figure 1.4 details our node statistics on how wealth β regression coefficient means (dots) and standard deviations (bars) change across talkspan and by initial population size (color). The Degree results indicate increasing social connectivity in small populations has an immediate and positive impact on wealth creation, yet those effects become negative as both technology proliferates and population size increases. This suggests not only diminishing marginal returns to increasing

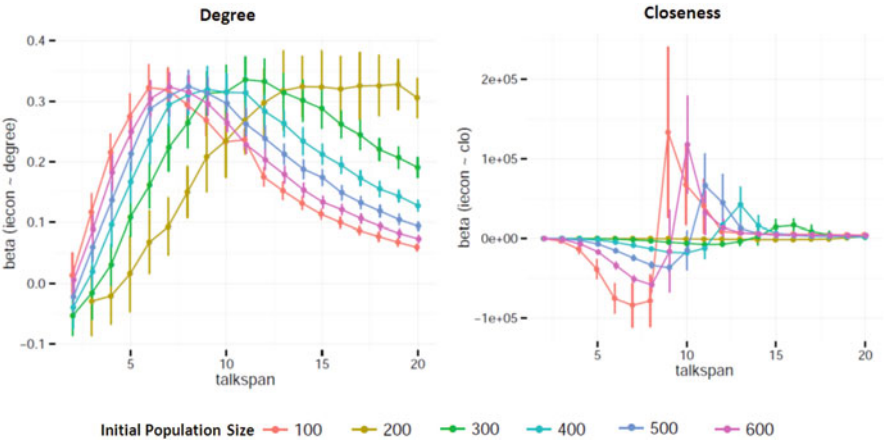

Fig. 1.4 Agent wealth elasticity with respect to technology and node level network statistics

communications' payoffs to individuals but moreover a crowding out effect. For Closeness, we find that agents with shortest path lengths, measuring the extent to which agents are near other transacting agents, is sinusoidal; negative and counter productive to wealth creation in low technology environments with a sharp phase transition to strongly positive, yet decreasing marginal returns as communications and technology proliferates.

This indicates quite different wealth maximization strategies and network placement tactics for individual agents depending on societal conditions. High connectivity via Degree or being well placed in brokering others' transactions can have a significant impact on both individual and societal wealth creation that changes over time and across societies of different sizes. As economic and social capital is created, past transaction histories tend to reinforce future success, and networks emerge and solidify at different rates depending on technology. This also suggest micro, agent level support for neo-classical macroeconomic theories of conditional convergence, where highly developed nations experience slow growth while developing nations can leapfrog more advance societies from a technology transfer perspective and converge on income levels.

6 Conclusions

Consistent with comparative political economy theory and empirical reality, our HDD model finds complexity and nonlinear path dependence in three areas: adaptive development processes, the emergence of co-evolutionary transaction networks and near equilibrium development trajectories. From a complex adaptive system perspective on HD theoretical processes, economic progress is a necessary condition for successful secularization and expressive political behavior, which are antecedents for lasting democratic institutions.

While political modernization is not inevitable, our results support empirical observations for a staged process where increasing existential security via economic development leads to increased emphasis on rational-secular and self-expressive values that results in societal development. Strategically, agents do adapt interactively with their environments as mutual cooperation does result in higher societal wealth than defection alone and is self reinforcing over time. From a network perspective, the emergence and persistence of preferred node positioning illuminates both individual wealth creation and societal development strategies. The impact of such behavior varies dramatically by both technology proliferation and population size, demonstrating social compression, competition and capital generation. Although only an initial, rough approximation at the truly complex, interdependent and highly nonlinear nature of modernization, our HDD approach provides insights into the interactivity of individual agency and societal outcomes seen through the lens of evolutionary games.

References

Abdollahian MA, Yang Z (2013) Towards trade equalization: a network perspective on trade and income convergence across the 20th century. New Polit Econ 18(3):1–27

Abdollahian MA, Coan T, Oh HN, Yesilada B (2012) Dynamics of cultural change: the human development perspective. Int Stud Q 56(4):827–842

Abdollahian MA, Yang Z, Coan T, Yesilada B (2013) Human development dynamics: an agent based simulation of macro social systems and individual heterogeneous evolutionary games. Complex Adapt Syst Model 1(1):1–18

Abdollahian MA, Yang Z, Neal PD (2014) Human development dynamics: an agent based simulation of robust adaptive heterogeneous games and social systems. In: Kennedy WG, Agarwal N, Yang SJ (eds) Social computing, behavioral-cultural modeling, and prediction: 7th international conference. Lecture Notes in Computer Science (LNCS). Springer, Switzerland, pp 3–10

Acemoglu D, Robinson J (2012) Why nations fail: the origins of power, prosperity, and poverty. Crown Business, New York

Axelrod R (1987) The evolution of strategies in the iterated Prisoner's Dilemma. In: Davis L (ed) Genetic algorithms and simulated annealing. Morgan Kaufman, Los Altos, pp 32–41

Axelrod R (1997a) The complexity of cooperation: agent-based models of competition and collaboration. Princeton University Press, Princeton

Axelrod R (1997b) The dissemination of culture: a model with local convergence and global polarization. J Confl Resolut 41:203–226

Barro R (1991) Economic growth in a cross section of countries. Q J Econ 106(2):407–444

Bell D (1973) The coming of postindustrial society. Basic Books, New York

Binmore KG (1994) Game theory and the social contract. MIT Press, Cambridge

Boix C, Stoke S (2003) Endogenous democratization. World Polit 55:517–549

Caselli F, Esquivel G, Lefort F (1996) Reopening the convergence debate: a new look at cross-country growth empirics. J Econ Growth 1(3):363–389

Darity W (2008) Social judgment theory. Macmillan Reference USA, Detroit

Diamond L (1992) Economic development and democracy reconsidered. In: Diamond L, Marks G (eds) Reexamining democracy. Sage, London

Eckstein H, Gurr TR (1975) Patterns of authority: a structural basis for political inquiry. Wiley, New York

Feng Y (2003) Democracy, governance, and economic performance: theory and evidence. MIT Press, Cambridge, MA
Gargiulo M, Benassi M (2000) Trapped in your own net? Network cohesion, structural holes, and the adaptation of social capital. Organ Sci 11:183–196
Griffin E (2009) A first look at communication theory. McGraw-Hill Higher Education, Boston
Gurr TR (1970) Why men rebel. Princeton University Press, Princeton
Inglehart R (1997) Modernization and postmodernization: cultural, economic and political change in 43 societies. Princeton University Press, Princeton
Inglehart R, Baker WE (2000) Modernization, cultural change, and the persistence of traditional values. Am Sociol Rev 65:19–51
Inglehart R, Welzel C (2005) Modernization, cultural change, and democracy: the human development sequence. Cambridge University Press, New York
Kauffman SA (1993) The origins of order: self-organization and selection in evolution. Oxford University Press, Oxford
Mankiw NG, Romer D, Weil DN (1992) A contribution to the empirics of economic growth. Q J Econ 107:407–437
McPherson M, Smith-Lovin L, Cook J (2001) Birds of a feather: homophily in social networks. Annu Rev Sociol 27:415–444
Moyano LG, Sanchez A (2013) Spatial prisoner's dilemma with heterogeneous agents. Elsevier Manuscript Atlanta, GA
Nowak MA, Sigmund KA (1993) Strategy of win-stay, lose-shift that outperforms tit-for-tat in the prisoner's dilemma game. Nature 364:56–58
Nowak MA, Sigmund KA (1998) Evolution of indirect reciprocity by image scoring. Nature 393:573–577
Oh H (2009) Using social network analysis for interpersonal comparison of utilities in behavioral games. PhD dissertation, Claremont Graduate University, Claremont
Quek HY, Tan KC, Abbass HA (2009) Evolutionary game theoretic approach for modeling civil violence. IEEE Trans Evol Comput 13:1–21
Sala-i-Martin XX (1996) Regional cohesion: evidence and theories of regional growth and convergence. Eur Econ Rev 40:1325–1352
Siero FW, Doosje BJ (1993) Attitude change following persuasive communication: integrating social judgment theory and the elaboration likelihood model. J Soc Psychol 23:541–554
Snijders TA, Steglich CE, Schweinberger M (2007) Modeling the co-evolution of networks and behavior. Longitudinal models in the behavioral and related sciences, pp 41–71
Solow R (1956) A contribution to the theory of economic growth. Q J Econ 70:65–94
Swan T (1956) Economic growth and capital accumulation. Econ Rec 32:334–361
Uzzi B (1996) The sources and consequences of embeddedness for the economic performance of organizations: the network effect. Am Sociol Rev 61:674–698
Uzzi B (1999) Embeddedness in the making of financial capital: how social relations and networks benefit firms seeking finance. Am Sociol Rev 64:481–505
Vespignani A (2009) Predicting the behavior of techno-social systems. Science 325:425–428
Welzel C, Inglehart R, Klingemann H (2003) The theory of human development: a cross-cultural development. Eur J Polit Sci 42:341–380
Wilensky U (1999) NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston
Yang Z, Abdollahian M (2014) Trade networks, regional agreements and growth. In: Deese D (ed) The international political economy of trade. Edward Elgar, Cheltenham
Zheleva E, Sharara H, Getoor L (2009) Co-evolution of social and affiliation networks. In: Proceedings of the 15th ACM SIGKDD international conference on Knowledge discovery and data mining, ACM, New York
Zhou X, Zhao W, Li Q, Cai H (2003) Embeddedness and contractual relationships in China's transitional economy. Am Sociol Rev 68:75–102