Human Development Dynamics: An Agent Based Simulation of Adaptive Heterogeneous Games and Social Systems

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Abstract. In the context of modernization and development, the complex adaptive systems framework can help address the coupling of macro social constraint and opportunity with individual agency. Combining system dynamics and agent based modeling, we formalize the Human Development (HD) perspective with a system of asymmetric, coupled nonlinear equations empirically validated from World Values Survey (WVS) data, capturing the core qualitative logic of HD theory. Using a simple evolutionary game approach, we fuse endogenously derived individual socio-economic attribute changes 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 economic development, cultural plasticity, social and political change.

Keywords: economic development, modernization, cultural shift, democratization, co-evolution, game theory, agent based model, techno-social simulation, complex adaptive systems.

1 Introduction

Rooted in comparative political economy, the HD perspective is a qualitative, trans-disciplinary 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 [1] 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 [26] 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. We posit a new, Human Development Dynamics (HDD) approach where agency matters.

In order to create a robust techno-social simulation [32], 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 [3-5] and Nowak and Sigmund [24, 25] to simulate intra-societal, spatial economic transactions where agents are capable of Robust Adaptive Planning (RAP). Understanding the interactive political-cultural effects of macro-socio dynamics and individual agency in intra-societal

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transactions are key elements of a complex adaptive systems (CAS) approach. We find strong epistatic interactions, where strategies are interdependent, and local social co-evolution [20] help determine 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 [17-19] [33].

HD theory expands upon economic drivers from neoclassical growth theory [30, 31] [6] commonly attributed to high growth paths and convergence [21] [27]. Such approaches specify detailed and interactive vectors of economic determinants, country and time-specific effects separately [10]; 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 [7] 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 [16] [13]. 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 [19].

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 [12] [9] [14] [2]. 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.

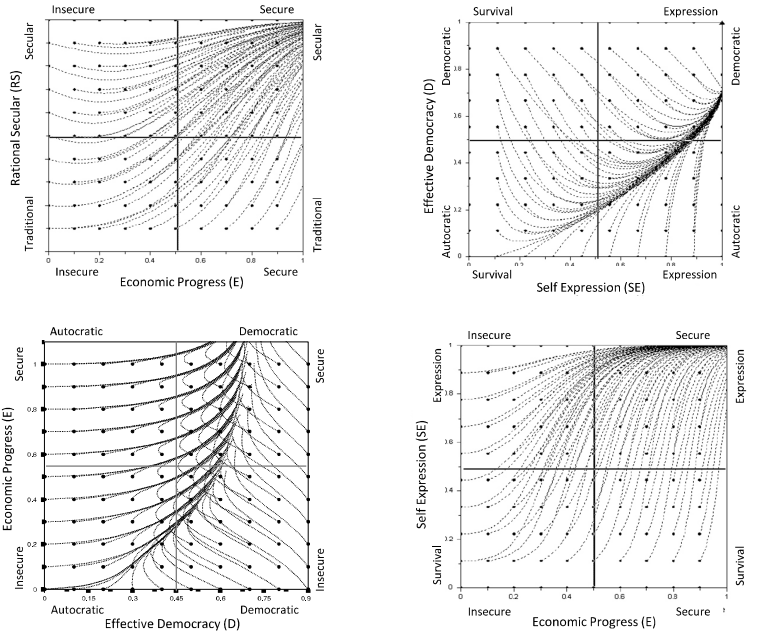

Fig. 1. HD Phase Portraits (Source: Abdollahian et al 2012)

3 A Human Development Dynamics Model

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 [8]. Geography and proximity are allowed to play a role by instantiating in random two-dimensional lattice worlds.

Social co-evolutionary systems allow each individual to either influence or be influenced by all other individuals as well as macro society [29] [35], 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 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.

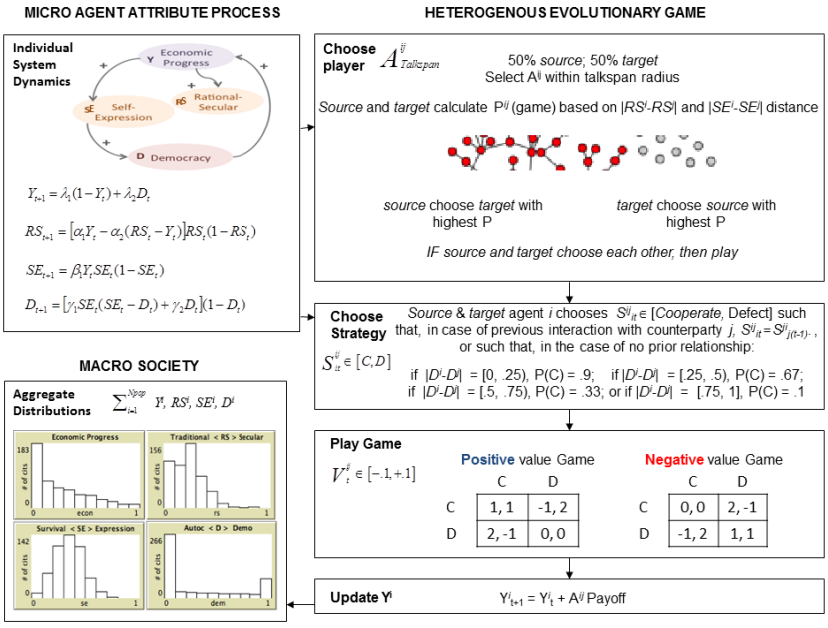

Fig. 2. HDD Architecture (implemented in NetLogo [34])

Following Social Judgment Theory, the attribute positions of two agents are conceived as a Downsian continuum [11] [15] 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 $|RS^i\text{-}RS^j|$ and $|SE^i\text{-}SE^j|$ within the given neighborhood. This captures communications and technology diffusion for frequency and social tie formation [22].

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 $|D^i\text{-}D^j|$ [28].

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 [20] [23].

Following Nowak and Sigmund [24], 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.

4 Sensitivity Analysis

In order to make more generalizable model inferences, Table 1 details the 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 magnitude and substantive effects across OLS β coefficients. The results reflect a quasi-global sensitivity analysis with 500 agents in180 runs and 700 iterations in each run, randomly down-sampled for pooled OLS tractability.

Table 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	78591	81982	73499	61877
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.

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. Talk-span spatial proximity is positive and significant, confirming priors that increasing technology and compressing potential social space also speed development processes. 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.

5 Conclusions

Consistent with qualitative HD theory and empirical reality, our HDD model finds complexity and nonlinear path dependence in three areas: adaptive development processes, social co-evolutionary transactions 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 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. Here we find that rational-secular norms strongly impact economic growth and speed up the pace of development more than self-expressive societal values alone. Beyond supporting HD theory, 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.

While 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. Perhaps techno-social simulations like HDD can assist policy makers and scholar alike, to better understand, anticipate and shape positive social outcomes for all.

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