ODD Specification of the Hohokam Trade Networks Model: Open vs Restricted Networks and the Distribution of Pottery from Specialist Producers to Consumers in the Phoenix Basin of Central Arizona

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Overview

Purpose. The purpose of this model is to understand how structural and process changes in exchange systems affected patterns of pottery distribution for the prehistoric Hohokam of the Phoenix Basin. The approach adopted was pattern-oriented modeling (Railsback and Grimm 2012), and the model developed for this research has several configurations to explore how open and restricted exchange networks may have resulted in different distributions of pottery. Fundamentally, this model is intended to encourage better interpretations of the archaeological record more so than it is about bringing a new perspective to a particular complex process through modeling and simulation. For the most part, it is a very simple, abstract model – but one informed with empirical real-world data. It is not a highly parameterized, highly realistic model of the Hohokam occupation or the broader Hohokam economy. Four discrete phases of the Hohokam sequence (spanning AD 200-1450) may be initialized and simulated, but importantly this model does not attempt to model the evolution of the Hohokam economy across the major structural changes that took place between those phases. The model was implemented in NetLogo version 5.1.

State Variables and Scales. The model is comprised of individual agents (Hohokam households) situated in an environment that is a highly abstracted but geographically accurate representation of the Hohokam Phoenix Basin. Household agents are differentiated by their location, occupation (farmer or pottery producer), exchange network(s), production capacity (dynamic), their pottery toolkit needs, and their intact or broken/discarded pottery assemblages. There are only two kinds of goods produced in the model economy: pottery and an abstract agricultural product. Rules defining the definition of agents' exchange networks are discussed in detail in the Details section below. Settlements in the model are simply clusters of household agents randomly distributed within a radius of one grid square centered on known coordinates for the actual sites. Tables 1-4 summarize the parameters and default settings built into the NetLogo model.

The world for this model encompasses the greater Phoenix Basin, including approximately 40 settlements in the lower Salt River and middle Gila River valleys. The exact number and location of occupied sites during a specific period is determined by the accompanying GIS shape file (sites2.shp). Archaeological estimates of the sizes of villages at different times (Table 3) inform the distribution of agents on the landscape (adapted from Doelle 1995, 2000; Nelson et al. 2010). Northernmost settlements included in the model are on the northern edge of Canal System 2; easternmost settlements are located on Siphon Draw (northeast of Queen Creek); westernmost settlements are the west ends of Canal Systems 2 and 7; southernmost settlements include the Snaketown area on the Gila River—though households at the Gila River villages were coded as pottery producing agents, not farmers. Spatial distance between sites is the only realistic feature of this landscape, otherwise it is devoid of topography or natural features such as rivers or mountain ranges.

While it was not relevant to the behaviors of agents in the model, two spatial scales were important when summarizing the output of the model: individual agents and settlements (archaeological sites). Differentiating these scales was necessary to document and compare patterns of pottery distribution from producers to consumers across those scales. Regardless of their settlement affiliation, all agents operated autonomously.

Temporally, the model was loosely designed such that each time step was analogous to an agricultural cycle in the Phoenix Basin. Given that there were at least two agricultural cycles per calendar year, and that each simulation was typically run to 400 time steps, the duration of the simulation was loosely comparable in scale to a 200-year phase. Because the model was very simple, abstract, and primarily focused on understanding patterns in the distribution of pottery, a structurally detailed and valid temporal aspect of the agent-based model was not particularly critical.

Process Overview and Scheduling. The processes built into the model are very simple. Agents have very strict rules about which goods to produce and how much of those goods to produce. The dynamics related to the exchange or trade of goods are only slightly more complex. Agents cannot move around the landscape; instead; pottery simply passes between buyers and sellers as instructed. Also, agents do not have any sort of life cycle in this model. All agents present when the model is initialized are present and active for the duration of a simulation.

Production of the two goods in the model, whether agricultural or pottery, is a discrete time process. Importantly, this is not a model of craft production. It is instead about trade and exchange. Behaviors in the model related to production are primarily defined to provide agents both the necessary goods to participate in the modeled economy and to introduce some purchasing power variability among the population of agents. Agents do not make any decisions regarding their occupation – either they produce pottery or agricultural goods, and that is determined when the model is initialized. At the beginning of each time step every agent makes a decision about how much to produce and those newly produced goods are simply added to their inventories. Production is dynamic but compressed: the agent checks its inventory, and if it is above or below its ideal threshold then it adjusts production slightly in the current time step to maintain production at a level that is in a reasonable range to participate in the economy. One difference between the farmers and the pottery producers is that the farmers have a 50 percent chance each time step that their crop will fail.

Consumption is also scheduled as a simple discrete time process. Every agent, regardless of occupation, consumes a set amount of agricultural produce every time step. Pottery consumption, analogous to the breakage and discard of a pot, potentially occurs every time step – though the probability of a farmer breaking a pot is relatively low (10 percent each time step). According to a farmer’s specific pottery toolkit thresholds, a broken pot may trigger the processes related to acquiring a replacement.

Exchange is characterized by very simple rules. Transactions (of agricultural goods for pottery) occur only within pre-established networks (described below). Prices are fixed, but there is a small transaction cost linked to distance charged to the buyer. The relative weight of the transaction is a global variable (d-weight) set by a slider on the NetLogo interface. The transaction cost was calculated as: (d-weight * distance in grid units from the seller)/10000. Agents are rational, and if there are multiple pots available in their network, they purchase the pot with the lowest cost. Agents with a surplus of pottery, more than their individually-assigned preferred count of pots, are eligible to sell those surplus pots to other agents. Only agents with a surplus of agricultural goods are eligible to purchase pottery. Agents who produce pottery maintain a relatively large inventory of pots that are always available to connected buyers.

Design Concepts

Emergence. The patterns of interest are the distribution of pottery in the Phoenix Basin given a simple economy abstractly modeled on the prehistoric Hohokam occupation of the region. Spatial distribution of farming and pottery producing households, exchange network topologies, and rule sets governing individual transactions are all finer-scale features of the model that shape far-flung and long-term patterns of distribution. That can be compared with empirical data from the archaeological record.

Sensing. Agents use distance between buyers and sellers to determine a transaction cost for the proposed exchange. Agents hoping to acquire pots also have access to information about pot availability from other agents in their defined exchange network.

Interaction. Agents in the model interact to exchange or trade agricultural goods for pottery. Regarding all other production and consumption processes the agents are discrete, fully autonomous entities.

Stochasticity. Stochasticity is important to the model, as many of the parameters are input as probabilities or ranges from which values are randomly selected. Some of these probabilities are drawn from empirical data or abstracted from ethnographic research. In several cases, though, the values and probabilities were selected for pragmatic reasons given other empirical input to the model. Fundamentally, stochasticity in the model generated output that adhered to the normal distribution and no effort was made to skew or truncate the dispersion of parameters affected by randomness. The randomized behavior in the model was important because a sample drawn from the simulation output was to be compared to a sample of real data from the archaeological record, and the stochasticity allowed for a better assessment of the model performance given known and unknown uncertainty in the samples.

Observation. For testing of the model, each process was observed at a very local scale (individual agents and pairs of agents involved in transactions). For later data collection experiments, output of pottery assemblages (counts of wares and forms in associated middens) from all farmer agents in the model was saved to a comma delimited text file and eventually aggregated at the site scale. Also, data regarding each farmer's exchange networks was documented and saved so that particularly good-fitting network structures could be reproduced.

Prediction. The model output far more virtual ceramic data for sites across the Phoenix Basin than was eventually compared to the empirical archaeological data. The output from better-performing sub-models may be useful for predicting the kinds and amounts of pottery that may be encountered at those sites if and when they are excavated and analyzed. Those data could effectively be used to further explore the validity of the best performing sub-models.

Details

Initialization. Depending on model settings for the archaeological phase, the model is initialized with a set number of farmer and producer agents distributed on the landscape according to the updated population estimates found in Doelle (1995, 2000) and Nelson et al. (2010). Those counts of agents are shown in Tables 1 and Table 3. Initial distribution of pottery from producers to farmers is a somewhat complicated process. First, farmers are initialized with no pottery, but producers begin with a large quantity of pottery. Pottery is then allowed to flow through the defined exchange networks for 1000 time steps before any data is collected on pottery distribution. After the 1000 time steps, the model is properly initialized and ready to proceed with the simulation and data output.

Input. As mentioned above, the primary empirical data informing the model is the farmer and producer locations and agent distributions drawn from published archaeological data and input as a GIS shape file. A handful of other parameters (e.g., bowl-to-jar ratios for producers, as shown in Table 4, or ideal pottery toolkits for farmers) were informed by empirical data or abstracted from ethnographic work and coded into the model, but in most cases those were implemented as randomized variables rather than concrete input data.

Submodels

Exchange Networks. Three exchange networks were built into the model, and each topology can be selected using a slider on the NetLogo interface. The degree distribution is reported on a bar chart on the interface. Net-type 1 is a scale-free network coded using a preferential attachment routine adapted to the current model from the NetLogo library. The resulting network follows a power law, with a small number of highly connected nodes and a large number of nodes having only one or two links. Spatial relationships of the agents are not considered. Net-type 2 is random-normal network where each agent has a 0.02 chance of connecting to all the other agents in the model. This attachment rule results in a normal degree distribution centered roughly on 1/50th of the total agent population. Spatial relationships of the agents are not considered, and typically this setting would result in agents having approximately thirty connections scattered all over the map. Net-type 4 is a spatially-weighted scale-free network. With this routine, agents consider distance as the single most important factor in building exchange networks. The code is structurally similar to the traditional preferential attachment algorithm, but uses distance instead of degree centrality to weight other agents.

Table 1. Counts of different agent types and related hierarchical levels.

Time Period	Count – Pottery Producers	Count – Producer Settlements	Count – Farmers	Count – Farmer Settlements
I+II	120	3	300	16
III	160	4	951	37
IV	200	5	1222	39
V	160	4	1743	38

Table 2. Overview of Processes, Parameters, and Default Values of Parameters of the Model.

Parameter	Value	Notes
Types of Agents	2	(farmers and producers)
Farmer Ideal Pottery Toolkit	5-7 pots, median 7	(evenly split between bowls and jars
Farmer Crop Failure Risk	.5 per time step	
Farmer Agricultural Production	(dynamic, updated per time step)	
Farmer Ideal Agriculture Inventory	10 units	
Farmer States	3	(seeking pottery, selling pottery, idle)
Pottery Production	(dynamic, updated per time step)	
Producer States	2	(selling pottery, idle)
Agricultural Produce Consumed	7.5 units per time step	
Exchange Network Topologies	3	
- Random		(0.02 chance connection to all other agents)
- Scale-free		
- Spatial Scale-free		
Trade Parameters		
- Distance weight multiplier	0-10	
Pottery		
- Vessel forms	2	(bowls and jars)
- Form ratios		(see table 5.1)
- States	2	(intact and broken)
- Breakage probability	.1 per time step	

Table 3. Sites and agents at sites in the model for the four time periods.

Site	TI+II	TIII	TIV	TV	Source*
Pueblo del Rio	0	10	20	40	mp
Villa Buena	20	50	50	50	mp
Las Cremaciones	20	30	30	40	mp
Lombeye Ruin	0	0	0	40	mp
Pueblo Viejo	30	50	50	70	mp
Casa Chica	0	0	0	40	mp
Las Moradas	10	10	0	0	jw
La Villa	30	25	0	0	jw
Pueblo Patricio	20	10	10	20	jw
Las Colinas	0	3	50	90	mp
Grand Canal Ruins	0	0	0	40	mp
Leo's Site	0	0	0	40	mp
Casa Buena	0	0	0	50	mp
Los Solares	10	30	20	0	mp
El Caserio	0	14	0	0	jw
La Lomita Pequena	0	10	10	0	jw
La Lomita	0	20	30	20	jw
Dutch Canal Ruin	0	26	2	0	jw
Pueblo Salado	0	0	0	20	mp
Las Canopas	20	40	50	50	mp
Pueblo de los Muertos	0	0	10	70	mp
Los Guanacos	0	30	30	50	mp
Las Estufas	0	0	40	20	mp
Hemenway Site	0	0	0	0	mp
Pueblo del Monte	0	0	20	30	mp
Los Hornos	20	40	50	50	mp
La Plaza	0	20	20	50	mp
Pueblo Grande	20	40	50	90	mp
El Caliche	0	30	30	0	mp
Stone Hoe Site	20	30	40	40	mp
Pueblo del Juan	0	20	30	40	mp
Tres Pueblos	0	0	20	40	mp
Pueblo Parvo	10	10	10	10	mp
East Pueblo Blanco	10	30	30	30	mp
Pueblo Blanco	0	20	0	40	mp
Mesa Grande	20	40	50	90	mp
Casita	0	0	0	40	mp
Las Acequias	0	0	0	50	mp
Casa Alma	0	30	30	0	mp
La Casa de Mesa	0	0	30	40	mp
Casa de Fe	0	0	30	0	mp
Casa de Enos	0	0	30	0	mp
Pueblo Maroni	0	30	30	40	mp
Casa de Omni	0	30	30	0	mp

Las Ruinitas	0	30	30	0	mp
Crismon Ruin	0	30	30	0	mp
Pueblo Primero	20	30	40	50	mp
Pueblo del Alamo	0	20	30	40	mp
La Ciudad	20	40	50	70	mp
El Canal	0	30	30	0	mp
Las Colinas loc 1	0	3	50	90	jw
Siphon Draw	0	30	0	3	jw
SW Germann	0	10	30	60	jw

* mp = Doelle 1995, 2000; Nelson et al. 2010. jw = Watts 2013.

Table 4. Bowl-to Jar ratios for different pottery sources.

Time Period	Source	Bowl Fraction	Jar Fraction
I+II	Mica Schist Plain Ware	.500	.500
	Phyllite Temper	.666	.333
	East South Mountain	.000	1.000
III	Mica Schist Buff Ware	.900	.100
	Mica Schist Plain Ware	.360	.640
	Las Colinas	.340	.660
	East South Mountain	.140	.860
IV	West South Mountain	.900	.100
	Mica Schist Buff Ware	.880	.120
	Mica Schist Plain Ware	.500	.500
	Las Colinas	.440	.560
	East South Mountain	.170	.830
V	Mica Schist Buff Ware	.830	.170
	Mica Schist Plain Ware	.490	.510
	Las Colinas	.600	.400
	Squaw Peak	.620	.380

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