Markets, Social Networks, and Endogenous Preferences[1]

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Abstract. This paper generalizes the Bell's model ("Locally interdependent preferences in a general equilibrium environment," JEBO, 2002), and models an interaction between a market, endogenous preferences, and a general social network. Contrary to Bell's results, 1) the system need not to converge, 2) the agents' preferences need not to be polarized, 3) the agents' preferences need not to adjust in the proportion to the availability (only the more abundant good can be consumed in one type of equilibrium), and 4) the agents with the same preferences need not to be clustered.

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1 Introduction

In economic theory, agents' preferences are usually taken as exogenous and fixed. While there are many appealing reasons for this approach, it seems more than likely that preferences of real-world people are endogenous, change over time, and are influenced by their social interactions. There is a growing body of literature on endogenous preferences and impact of social networks on economic behavior. One of the studies in the preference adaptation in the context of social networks is A. M. Bell's seminal paper "Locally interdependent preferences in a general equilibrium environment" [1]. In this paper, Bell explored the evolution of agents' preferences by means of an agent-based simulation. In her basic model, the prices of two goods were set in a centralized market. The agents' preferences were endogenous: the agents increased their taste for the good that was consumed more in their local neighborhood. In equilibrium, each agent consumed only one of the goods, the agents with the same preferences were geographically clustered, and fewer agents specialized in consumption of the scarcer good.

Bell simulated her model only for one size and one type of social network (the grid). Therefore it is not known whether her findings generalize for other sizes and types of networks. It is also not known whether her findings were caused by the centralized market, the social network, or their interaction. The purpose of this study is to extend Bell's model to find answers to these two questions. To do it, the basic version of Bell's model (the model with a given endowment and no production) will be extended and simulated for various sizes and types of networks and their parametrization. It will be explored how much the characteristics of the resulting equilibrium depend on the characteristics of the social network. One special case discussed is *disconnected* agents. This will help us to understand what part of the Bell's findings are caused by the social network, and what are caused by the centralized market. It will be shown that many of Bell's results have to be modified.

2 Model

The used model is a straightforward generalization of the Bell's model of "exchange economy", see [1]. The only change is that the implicit grid network was replaced with the explicit description of a general social network. In general, the agents consume two kinds of goods (e.g. black and white t-shirts) which are comparable, i.e. their total consumption has a natural meaning (how many t-shirts an agent consumes). In every period, all agents get an initial endowment of each good. Then they trade these goods with each other at the centralized market at the market clearing price. The agents' preferences evolve over the time: each agent increases her preference for the good that has been recently more popular (i.e. more consumed) in her neighborhood. Her neighborhood consists of the agent herself and the agents she has relationship with. The set of all relationships in the population forms a social network.

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More formally, there are N agents indexed $i = 1, \ldots, N$. In every period, each agent gets the same endowment: e_1 units of good 1 and e_2 units of good 2 ($e_1 \leq e_2$). Agent i then demands x_{i1} unit of good 1 and x_{i2} units of good 2 to maximize her one-period Cobb-Douglas utility function subject to the constraint given by her endowment, i.e.

$$\max_{x_{i1}, x_{i2}} x_{i1}^{a_{it}} x_{i2}^{1-a_{it}} \qquad \text{s.t.} \quad p_1 x_{i1} + p_2 x_{i2} = p_1 e_1 + p_2 e_2, \tag{1}$$

where p_1 and p_2 are the prices of good 1 and good 2 respectively, and a_{it} is agent i's relative preference for good 1 at time t. The initial value of the preference parameter a_{i0} is drawn independently for each agent from the continuous uniform distribution $U(0, 1)$.

Agent i's demand for the two goods is then

$$x_{i1}(p_1, p_2) = a_{it}\left(e_1 + \frac{p_2}{p_1} e_2\right), \qquad x_{i2}(p_1, p_2) = (1 - a_{it})\frac{p_1}{p_2}\left(e_1 + \frac{p_2}{p_1} e_2\right). \tag{2}$$

Since the total endowment is given, the market clearing relative price is

$$\frac{p_1^*}{p_2^*} = \frac{e_2 \sum_{\forall j} a_{jt}}{e_1 \sum_{\forall j}(1 - a_{jt})} \tag{3}$$

The social network is represented by an undirected graph G, in which agents are vertices and their relationships are edges (connections). Two agents i and j have a relationship if they are connected with an edge; we then write $i \sim j \in G$. We define the agent i's neighborhood $n(i) = \{j : j = i \vee j \sim i \in G\}$, i.e. as the set of indices of all agents who are connected to agent i and the index of the agent i herself. The social network is for each simulation created randomly by a given algorithm; it is fixed within the simulation.

After observing the consumption in her neighborhood, each agent adjusts her preferences in such a way that she increases the preference for the good that is consumed more in her neighborhood. Specifically, agent i sets the future value of her preference parameter $a_{i,t+1}$ at

$$a_{i,t+1} = a_{it} + r\left(\frac{\sum_{j \in n(i)} x_{j1}}{\sum_{j \in n(i)} x_{j1} + \sum_{j \in n(i)} x_{j2}} - 0.5\right) \tag{4}$$

where the adjustment parameter $r \in (0, 1)$ regulates the speed of the preference adjustment.

The evolution of agents' preferences and consumption is simulated in the agent-based computational fashion (for introduction to it, see e.g. [3]). First, the model is initialized: a given social network consisting of N agents is created (see [5] for the network-creation algorithms), and each agent is assigned a random initial preference $a_{i,0}$ drawn from $U(0, 1)$. The simulation than proceeds in steps repeated until the model converges (i.e. the agents' preference parameters change no more), or the maximal amount of steps is reached. In each step, 1) the market clearing relative price p_1^*/p_2^* is calculated for the agents' current preferences (equation 3), 2) each agent's equilibrium consumption is calculated (equation 2), and 3) the agents' preferences are adjusted (equation 4).

3 Results of simulations

The model has been simulated for $N = 12, 25, 100, 156, 506, 992, 1980, 2500$ agents and the following standard types of network (see Figure 1 for the intuition or [5] for a detailed description of the networks): *grid* on torus, *star*, *ring*, *tree*, *small world*, *power* network, *complete* network and *disconnected* agents (for the *complete* network, the maximal N was 992 because the used simulation software was not able to carry more connections). In the ring network and initial small world network, each agent could have a connection with 2, 4, 6, or 8 closest agents. In the tree network, each agent could have 2 to 5 outgoing connections. In the power network, each agent was created with 1 to 5 new connections. The rewire probability in the small world network was $0.05, 0.1, 0.25, 0.5$. The endowment of good 1 was $e_1 = 1, 5, 10, 20, \ldots, 90, 95, 99, 100$, while the endowment of good 2 was $e_2 = 100$. The adjustment constant r was set to 0.5 as in [1]. The model has been simulated thirty times for each feasible combination of parameters. The maximal amount of simulation steps was set to 10 000. The total number of the simulation runs was 123 900. The model was simulated in NetLogo 5.0 [4]. The simulation results have been analyzed in R [2].

Since the full parametric space of the simulation is huge and non-rectangular, only the most salient stylized facts will be presented here. Specifically, the possible outcomes of the simulations, the role of the market and the interactions in the social network, clusters, and the determinants of the relative price will be discussed.

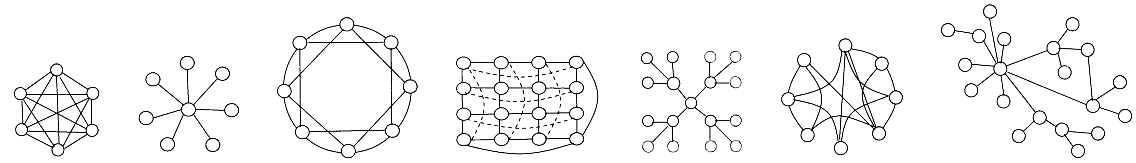

Figure 1 Examples of the network structures. The figures are taken from [5]. The grid is depicted as von Neumann neighborhood only for simplicity; Moore neighborhood was used in simulations.

3.1 Possible simulation outcomes

Bell [1] discusses only two kinds of simulation outcomes, both very similar. In both, the system converges, each good is consumed by some agents, and fewer agents consume the scarcer good than the more abundant one. The difference between the outcomes lies in the agents' equilibrium preferences. In the first case, each agent specializes in consumption of only one kind of good (i.e. $a_{it} \in \{0, 1\}$), while in the second case, at least some agents consume both goods (i.e. have $a_{it} \in (0, 1)$). Bell claims that the second outcome is unstable, and hence cannot occur in a simulation [1, p. 321]. Indeed, all Bell's simulation outcomes were of the first kind (she calls it "polarized").

My more general simulations produced a richer set of outcomes. There were four states: 1) the simulation did not converged (0.205 % of runs), 2) it converged but some agents remained non-polarized (0.220 % of runs), 3) the simulation converged, all agents were polarized but consumed only the more abundant good (13.835 % of runs), and 4) the simulation converged, all agents were polarized and both kinds of good were consumed by some agents which is the Bell's only outcome (85.739 % of runs). Since the above stated frequencies are somewhat artificial, it is instructive to decompose them.

Let us start with the state 1, the non convergence. This only occurred when the endowment of the two goods was precisely the same (i.e. $e_1 = e_2$), the network was either *complete* or *star*, and the number of agents was relatively large. In particular, the simulation of *complete* network always converged with $N = 12$ and in 93.333 % of runs with $N = 25$; otherwise it did not converge. The simulation of *star* network always converged with $N = 12, \ldots, 100$; then the frequency of the converged runs decreased with the number of agents: 93.333 % of runs with $N = 256$ converged, 70 % of runs with $N = 506$, 40 % of runs with $N = 992$, 33.333 % of runs with $N = 1980$, and 10 % of runs with $N = 2500$. It is interesting that these two types of network are in a sense opposite to each other and the reasons why they do not converge are opposite too. In the *complete* network, all agents are symmetric. If the network does not converge, it is because each agent interacts directly with all other agents and there is no "locality". Thus any change of an agent's preferences forces all other agents to change their preferences, which makes the next adjustment necessary, and so on. In theory, there can be both many polarized and non-polarized equilibria (e.g. one half agents prefer good 1 and the other half prefer good 2, or each agent's preference is 0.5 etc.) but all these equilibria are very fragile. In the *star* network, one central agent is connected to all other (branch) agents, while each branch agent is connected only to the central agent. The branch agents tend to be polarized in this case—roughly one half of them prefers good 1 and the other half good 2. It is the central agent who wavers between the two and thus precludes the convergence.

The state 2, converged but not-polarized, occurred most often when the endowment of the two kinds of good was the same too—96.703 % of runs in this state occurred when $e_1 = e_2$. However, it occurred with other proportions of the endowment too, even though only rarely. Most often this state occurred when $e_1 = e_2$, the network was either *complete* or *star*, and number of agents was small. All runs in the *complete* network with $N = 12$ and 6.667 % of runs with $N = 25$ ended in this state. (No other run on the *complete* network converged, see above.) As for the *star* network, all runs with $N = 12, \ldots, 100$, 93.333 % of runs with $N = 256$, 70 % of runs with $N = 506$, 40 % of runs with $N = 992$, 33.333 % of runs with $N = 1980$ and 10 % of runs with $N = 2500$ ended in this state. Beside these, two other networks (*power* and *small world*) tended to end up in this state. With few agents and many connections, these networks are close to the *complete* network. Usually, the *power* network ended in this state when $e_1 = e_2$ and $N = 12$. The frequency of this state raised with the number of connections from 3.333 % with 2 connections to 46.667 % with 5 connections. The *power* network with 5 connections ended in this state once also with $N = 25$ and once with $N = 256$ and $e_1 = 0.8e_2$. The *small world* network ended in this state most often with $N = 12$ and $e_1 = e_2$; however, it ended in this state several times even with other configuration, e.g. with $N = 1980$ and $e_1 = 0.5e_2$. Beside these, only *tree* network ended in this state once with $N = 25$ and $e_1 = 0.5e_2$. In general, the results for this state suggest that even though the non-polarized state is fragile, it can arise from the simulation, especially if the number of agents is small. It is also possible, that the runs denoted as “non-convergent” might have converged if the simulation was given more time.

The state 3, the converged polarized state where only the more abundant good 2 is consumed, occurred with any network including the *disconnected* one. However, with *disconnected* network, this state occurred only when the amounts of the two goods were extremely asymmetric ($e_1 = 0.01e_2$ or $e_1 = 0.05e_2$) and the number of agents was small ($N = 12, \ldots, 100$ when $e_1 = 0.01e_2$ and $N = 12$ in the other case). With increase in the endowment of good 1 or the number of agents, the frequency of state 3 decreases and soon vanished with the *disconnected* network. The situation was dramatically different with *complete* network. With it, the state 3 occurred always when $e_1 < e_2$ no matter what was the number of agents. The behavior of other networks was between these two extremes. In general, the increase in the endowment of the scarcer good e_1 or in the number of agents decreased the probability that all agents consumed only good 2. However, individual networks somewhat differed in their propensity to this state. Paradoxically, *grid* network used by Bell was relatively more prone to end up in this state than most other networks, with exception of *complete* and *star* networks and *small world* network with the comparable number of connections. Surprisingly, the closest to the behavior of *complete* network was again *star* network. The overall probability that the state 3 occurs can be modeled with the logistic regression. The results are summarized in Table 1. The presence of a social network increases the probability that only the more abundant good 2 is consumed (all network dummy variables coefficients are positive). The rise in the number of agents or in the amount of the scarcer good decreases the probability, while the rise of the average number of connections between agents increases it.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	−1.5718	0.1233	−12.75	0.0000
grid network	3.3075	0.1363	24.26	0.0000
power network	2.3564	0.1263	18.66	0.0000
small-world network	2.4546	0.1241	19.78	0.0000
ring network	2.6996	0.1269	21.28	0.0000
star network	4.5173	0.1359	33.23	0.0000
tree network	1.3319	0.1290	10.33	0.0000
complete network	10.4102	0.1689	61.62	0.0000
number of agents	−0.0013	0.0000	−65.32	0.0000
endowment e_1	−0.0796	0.0007	−108.29	0.0000
average number of connections	0.0018	0.0002	7.13	0.0000
log likelihood: −25089.08, McFadden’s pseudo R^2: 0.496, correctly predicted: 92.65 %				

Table 1 Binary logit model. Dependent variable is one if the state is state 3—converged, polarized, and only the more abundant good is consumed; otherwise it is zero. Network dummy variables are in contrast to *disconnected* agents. The average number of connections in the tree network is only approximate. Only data from the converged runs were used.

3.2 Role of market and of social network

Bell claims that “the number of agents consuming a good in the steady state is proportional to the availability of the goods. . . ” [1, p. 311]. If this was true, the relative price p_1/p_2 would be close to unity with no regard to the proportion of the endowments as long as $e_1 > 0$ and $e_2 > 0$. Bell does not attempt to judge what part of this result is caused by the centralized market and what part is caused by the interactions on the social network. She only claims that “the price acts as a negative feedback mechanism that limits consumptions of scarce . . . goods and encourages consumption of plentiful . . . goods” [1, p. 311]. Similarly, the “bandwagon” effect of the preference adjustment in the social network creates a positive feedback mechanism: if one good is more abundant than the other one, the agents can see it more often, and learn to like it more. (The previous section shows that the bandwagon effect can be so strong that all agents learn to consume only the abundant good, and throw away the scarce one, which contradicts the Bell’s claim stated above.)

Disconnected agents were included among the networks to allow to disentangle the impact of the two types of feedback: *disconnected* “network” includes only the market negative feedback; the rest networks include both the negative feedback and the bandwagon positive feedback. Their impacts can be seen either in the relative price p_1/p_2 or in the relative consumption, i.e. the average consumption of the agents who consume only good 1 divided by the average consumption of the agents who consume only good 2. However, the later is not necessary since it is the reciprocal value of the former. It is because all agents have the same endowment e_1 and e_2, and hence the same income $p_1e_2 + p_2e_2$. (The relative price $p_1/p_2 = 0$ means that no agent consumes the scarcer good 1, and hence the relative consumptions is not defined in this case. For this reason, the relative price p_1/p_2 will be used in the analysis.)

It is the market negative feedback (together with the preference-adjustment algorithm) what brings the system into an equilibrium (*disconnected* "network" always converges). In the equilibrium, usually both goods are consumed (the state 3 occurs least often with *disconnected* agents). And it is this force that presses the relative price p_1/p_2 to unity. The left part of Table 2 shows that the scarcer good 1 is usually more expensive than the more abundant good 2 ($p_1/p_2 \geq 0$) when agents are disconnected but as e_1/e_2 and the number of agents raises, the market negative feedback is able to push the relative price p_1/p_2 to unity. The consumers of the scarce good 1 have in average lower consumption that the consumers of the abundant good 2 in this case.

The presence of a social network adds the bandwagon effect which destabilizes the network (and possibly creates the clusters, see below). First, the bandwagon effect can preclude the convergence and increases the probability that the non-polarized state 2 occurs when the system converges (see above). Moreover, it raises the demand for the more abundant good and thus increases its price. The right part of Table 2 shows the example of the relative price for the *grid* network: it is almost always below unity, which means that the bandwagon positive feedback usually more than offsets the stabilizing impact of the market negative feedback. In the limit case, the scarcer good 1 is not consumed at all and its relative price $p_1/p_2 = 0$. If the scarce good 1 is consumed at all, its consumers have higher consumption than the consumers of the abundant good 2 in this case.

	disconnected							grid						
N / e_1	1	5	10	20	95	99	100	1	5	10	20	95	99	100
12	1.82	1.60	1.57	1.56	1.16	1.14	1.15	0.00	0.00	0.00	0.00	1.05	1.01	1.00
25	0.98	1.52	1.66	1.60	1.15	1.16	1.15	0.00	0.00	0.00	0.00	0.98	1.06	1.05
49	1.40	1.64	1.85	1.62	1.05	1.04	1.03	0.00	0.00	0.00	0.48	0.96	0.99	1.02
100	1.67	1.70	1.71	1.55	1.03	1.01	1.00	0.00	0.00	0.46	0.57	0.97	1.00	1.01
256	1.40	1.64	1.74	1.53	1.00	1.00	1.00	0.00	0.48	0.58	0.61	0.95	0.97	0.97
506	1.34	1.77	1.75	1.58	1.01	1.00	1.00	0.00	0.59	0.59	0.62	0.96	0.98	0.99
992	1.29	1.74	1.73	1.55	1.01	1.00	1.00	0.00	0.59	0.62	0.63	0.96	1.01	1.01
1980	1.33	1.77	1.73	1.56	1.01	1.00	1.00	0.00	0.60	0.61	0.66	0.94	0.97	0.97
2500	1.36	1.79	1.75	1.56	1.01	1.00	1.00	0.00	0.59	0.60	0.66	0.95	0.99	0.99

Table 2 Average relative price p_1/p_2 for selected endowments e_1 (columns), number of agents N (rows), and networks (panels). Averaging can bias the relative price slightly upward. Only data from states 3 and 4 were used in the computation.

3.3 Clusters

Bell reported that the agents with the same preference were clustered together in the polarized equilibria. This is indeed what happens in the polarized equilibria in the networks in which each agent has many connections (e.g. *grid* network). Each agent can retain her preference only if the number of the agents with the same preference is in her neighborhood higher than the number of agents with the opposite preference, i.e. if the agents are clustered. This, however, is not necessary in networks where some agents have only one connection (e.g. in *tree* network). There might survive also agents who have preference different from their surroundings. The sufficient condition is that 1) the dissenting agent i has only one connection, prefers the cheaper scare good 1 ($p_1/p_2 < 1$), and hence has higher consumption than the consumers of the more abundant good 2, and 2) agent j in the neighborhood $n(i)$ of agent i has more than one connection and she and most other agents in her neighborhood $n(j)$ consume the expensive abundant good 2, and hence have lower consumption than agent i. In this case, there can survive consumers of the scarce good 1 outside clusters; there even need not to be any clusters at all. This also explains relatively higher resistance of this type of networks against the state 3.

3.4 Quantitative determinants of relative price

The type and size of the social network do not affect only the qualitative, but also the quantitative characteristics of the equilibrium. Table 3 shows the determinants of the relative price p_1/p_2. The presence of the social network lowers the relative price. The rise in the number of agents and the endowment e_1 of the scarce good 1 brings the relative price to unity (notice that the corresponding parameters for the social network and *disconnected* agents have the opposite signs). Obviously, the used type of network strongly affects the equilibrium relative price.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.63	0.03	54.28	0.00
grid network	-1.37	0.03	-45.23	0.00
power network	-1.44	0.03	-47.89	0.00
small-world network	-1.35	0.03	-44.84	0.00
ring network	-1.27	0.03	-42.01	0.00
star network	-1.67	0.03	-54.71	0.00
tree network	-1.24	0.03	-41.30	0.00
complete network	-1.98	0.03	-64.68	0.00
number of agents	-0.00	0.00	-2.02	0.04
endowment e_1	-0.01	0.00	-18.85	0.00
average number of connections	-0.00	0.00	-5.04	0.00
number of agents × social network	0.00	0.00	6.01	0.00
endowment e_1 × social network	0.01	0.00	41.00	0.00
s: 0.2422, R^2: 0.6145, adjusted R^2: 0.6144, F: 1.6380 on 12 and 123360 DF, $p < 2.2e-16$				

Table 3 Linear regression model. Dependent variable is the relative price p_1/p_2. The network dummy variables and their summary “social network” are reported in contrast to *disconnected* agents. The robust standard errors of the parameter estimates are reported. The average number of connections in the tree network is only approximate.

4 Conclusions

The simulation results show that Bell’s conclusions have to be somewhat modified. There are more possible outcomes than she expected: the system need not to converge, the agents’ preferences need not to be polarized, and the number of agents consuming a good need not to be “proportional to the availability”—the agents can consume only the abundant good and throw away the scarce one. The agents need not to be clustered. In general, the convergence to an equilibrium, the type of the resulting equilibrium, and the equilibrium relative price are quite sensitive to the type and size of the used network because it is the bandwagon effect what destabilizes the system. This means that a careful specification of the social network might be crucial for modeling real-world markets.

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