Keeping up with the neighbors: social interaction in a market economy

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Abstract

We consider a world in which individuals have private endowments and trade in markets, while their utility is negatively affected by the consumption of their neighbors. Our interest is in understanding how social structure of comparisons, taken together with the familiar fundamentals of the economy – endowments, technology and preferences – shapes equilibrium prices, allocations and welfare.

We show that equilibrium prices and consumptions are a function of a single network statistic: centrality. An individual's 'centrality' is given by the weighted sum of paths of different lengths to all others in a social network. In particular, prices are proportional to sum of centralities, while an individual's consumption depends on how central she is relative to others in the network.

Inequalities in wealth and connections reinforce each other in markets: a transfer of resources from less to more central agents raises prices. As segregated communities become integrated the poor lose while the rich gain in utility!

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1 Introduction

Production, consumption and exchange take place at the intersection of society and markets. Traditionally, economists have concentrated on understanding how markets work. In recent years, there has been a resurgence of interest in social interaction. This work has generated an array of models to study economic questions; for the most part, however, these models focus on social interaction and almost entirely abstract from prices and market competition.[1] As the field of social networks matures we believe it is important to integrate the new models of social interaction with classical models of markets and price formation. This general view informs the approach we take in the present paper to study the effects of relative consumption concerns.

One of the recurrent themes in the study of individual well being is that, in addition to own consumption, it depends on the consumption of others with whom we interact and compare ourselves. But the happiness and therefore the consumption of these "close by" others in turn depends on the consumption of their friends and so on. Individual decisions on consumption are therefore shaped by the overall pattern of connections which obtain in the society. In order to understand consumption and welfare we therefore need a framework which takes account of social structure along with the familiar fundamentals of the economy – endowments, technology and preferences.

We consider a pure exchange economy with a finite set of agents who are price takers. Local social influences are reflected in the assumption that individual well-being is affected by the consumption of a subset of others, viz. their *neighbors*. Our interest is in understanding how social connections affect market equilibrium prices, allocations and individual utility.

We start our analysis in a benchmark model in which all agents have the same endowments so as to focus on the pure effects of social connections. We show that equilibrium prices and consumptions are a function of a single network statistic: *centrality*.[2] In equilibrium, individual consumption can be expressed as a function of her centrality in a social network, while the price is proportional to the average network centrality of agents in the network. As we add links to a social network, there are more (and shorter) paths between agents, so the sum of centralities rises and this pushes up prices.

We then extend our model to allow for wealth heterogeneity. Our main finding here is that wealth and network heterogeneity reinforce each other: a transfer of resources

[1] An important and early exception to this is Montgomery (1991), for recent work which seeks to integrate social structure and markets, see Cassella and Hanaki (2006) and Galeotti (2007). Goyal (2007) provides an overview of the recent research on social networks in economics.

[2] An individual's 'centrality' is given by the weighted sum of paths of different lengths to all others in a social network. For an early discussion of such centrality measures in the social sciences, see Katz (1953) and Bonacich (1987).

from a poorly connected to a well connected agent raises prices and alters allocations and utility across the economy. We then explore an important theme in the recent happiness literature: the role of shifting social interactions. We illustrate through examples, how poorly endowed individuals lose, while well endowed individuals gain, as we move from a society which is segregated (along economic class) to an integrated society.

These results are obtained in a setting where individuals care about aggregate consumption of neighbors. In our view this is a reasonable model to study: consider a person who takes vacations locally and compares herself to neighbors who travel to exotic destinations for vacations. It is plausible to suppose that she would feel worse off if she has ten such neighbors as compared to the situation in which she has only one such neighbor. Most of the existing literature (see references below) assumes that individuals care about the average consumption of society at large. The local counterpart of this formulation is one in which individuals care about the average consumption of their neighbors. With this literature in mind, and partly as a way to test the robustness of our results, we then turn to a study of market equilibrium in the presence of local average comparisons.

We show that, as in the basic model, equilibrium prices and allocations can be expressed a function of network centrality (weighted by endowments). An interesting insight pertains to the special case where endowments are identical: we find that prices and allocations *do not* depend on the network. This is in contrast to the outcome under aggregate social comparisons. However, if endowments vary, then we recover the earlier result, and networks do matter. One interpretation of this result is that networks matter only if there are other heterogeneities in the economy. Moreover, wealth heterogeneities reinforce network inequalities: so a transfer from less to more central agents raises prices, as in the basic model. The effect of a new link on prices depends on the consumption of new neighbors as compared to average of existing neighbors. If the new neighbors consume more (less) than existing neighbors then a link raises (lowers) demand and prices. Observe that this differs from the outcome in the basic model, where adding links generally raises prices. Finally, as a segregated society integrates, we find that the poor lose while the rich gain. This is analogous to the finding in the basic model.

There is a vast literature in economics, as well as in other disciplines, on the importance of relative consumption for individual well being. Perhaps, the best known early work is Veblen's (1897) critique of conspicuous consumption. In recent years, relative consumption concerns have been presented as the natural explanation to account for the Easterlin puzzle: the observation that happiness is positively related to incomes in a society at any point in time, but that increases in income in the society over time, appear to have little effect on happiness. **XYZCHECK** Recent papers by Kuhn et al (2008) and Luttmer (2005) present clear empirical evidence in support of the role of social effects on personal consumption and happiness. Kuhn et al (2008) find that an increase in the incomes of neighbors have significant effects on individual consumption patterns, and moreover that these effects are stronger for immediate neighbors as compared to general neighborhood effects. Luttmer's (2005) work suggests that changes in the incomes of neighbors have effects on self-reported levels of individual happiness and moreover the magnitude of these effects depends on the frequency of interaction with the neighbors.

Over the years, a number of models on relative consumption concerns – both at a personal level (across different selves of an individual, over time) as well as at a social level (across different individuals) – have been proposed; see, e.g., Abel (1990), Arrow and Dasgupta (2007), Easterlin (1974), Cres, Ghiglino and Tvede (1997), Frank (1985, 2007), Frey and Stutzer (2002), Hopkins and Kornienko (2004), Layard (2005), Blanchflower and Oswald (2004), de Tella, MacCulloch and Oswald (2003), Veblen (1899) and Dussenbery (1949). While these models differ in many ways, they share one common feature: they suppose that individual utility or well being depends on own consumption and *average* social consumption. However, the motivation for relative consumption effects in this literature typically arises at a local level, i.e., when we compare our consumption with the consumption of friends, colleagues and relatives. This formulation of average consumption is also restrictive from a substantive point of view as it precludes the study of changing patterns of social interaction, a subject which has been the topic of public debate (see e.g. the discussion in Layard (2005)). These considerations motivate our attempt at developing a framework in which local consumption effects can be studied systematically.[3]

Our paper builds on two earlier papers, Ballester, Calvo-Armengol and Zenou (2006) and Tan (2006). Tan (2006) studies the effect of social networks in a general equilibrium model. There are two main differences between the papers. One, he looks at specific networks – such as star and regular networks – while we allow for arbitrary networks. We develop general results on the interaction between endowment heterogeneity and social networks in market equilibrium; to the best of our knowledge these results are new.

Ballester, Calvo-Armengol and Zenou (2006) study a game of social interaction and derive a relation between Nash equilibrium actions and network centralities. While our work uses similar measures of network centrality, the motivation of our paper and the principal findings are quite different from their work. Moreover, in our paper, a key issue is how social structure and endowment heterogeneity complement each other in defining prices and utilities. On a technical note, we also note that our characterization of equilibrium obtains for all levels of social consumption effects.

[3]There is also an interesting line of research which examines the effects of trading restrictions – modeled in terms of networks – on equilibrium outcomes. See e.g., Gale and Kariv (2007), Kranton and Minehart (2001), and Kakade, Kearns, and Ortiz (2005).

This is in contrast to the Ballester et. al. (2006) result, as well as most of the literature that follows this paper, which requires the social effects to be small.[4]

The rest of the paper is organized as follows: section 2 sets out the basic model of consumption externality and section 3 solves this model. Section 4 takes up a model in which individuals care about the average consumption of their neighbors. Section 5 concludes.

2 Model

We consider a pure exchange economy populated with N consumers, $i = 1, ..., N$. Let $N(i)$ be the set of neighbors of consumer i and let $n_i = |N(i)|$. There are two consumption goods. Consumers care about their own consumption of good 1 and good 2. We note x_i the consumption of good 1 by agent i and y_i the consumption of good 2 by agent i. Consumers also care about the consumption of good 2 by their direct neighbors, i.e. consumer i cares also about $\{y_j\}_{j \in N(i)}$. Consumer i is endowed with a bundle of the two goods (ω_i, ν_i), where $\omega_i > 0$ and $\nu_i > 0$. We will represent the pattern of neighborhoods by G, which is a $n \times n$ matrix of 1's and 0's. An $\{i, j\}$ square in this matrix takes value 1 if and only if i and j are direct neighbors. We will assume that in this matrix the diagonal terms are all set equal to 0.

In order to model interpersonal comparisons in consumption we let the utility depends on own consumption in the two goods as well as neighbor's consumption in the second good. We will assume that:

$$U_i(x_i, y_i, y_{-i}) = u_i(x_i, \Phi(y_i, y_{-i})) \tag{1}$$

where $\Phi : R \times R^{n_i} \to R$ and $-i$ is the set of neighbors to agent i. Throughout this paper, we will suppose that individuals care about consumption of good y by others,

[4] After we had written our paper, we became aware of three new papers which study related ideas Bramoulle, Kranton and D'Amours (2008), Bloch and Querou (2008) and Mookherjee, Napel and Ray (2008). We briefly discuss the latter two papers, as they relate to social interactions and markets. Bloch and Querou (2008) study optimal discriminatory pricing by firms to consumers who experience consumption externalities with respect to their neighbors. They obtain a number of results which relate network centrality of individuals to optimal prices. Mookherjee, Napel and Ray (2008) study a model where families invest in the skills of children and these children then earn wages. The incentives to invest in human capital is related to the average wage in the local social environment. Their main results pertain to the existence of equilibrium in which communities with low and high human capital emerge due to due to the complementarities in the acquisition of human capital across created by the comparison of wages. So, while these papers deal with related themes the economic contexts they study are quite different and a detailed discussion of the results is not meaningful.

but do not care about their consumption of good x. This is the theoretically interesting case to consider; see Frank (2007) for an interesting discussion on the difference in social sensitiveness across goods. If consumption externalities are symmetric for both goods, then the social comparisons will simply wash out and equilibrium will be analogous to the equilibrium in an economy with no consumption externalities. This is analogous to a point made in a recent paper by Arrow and Dasgupta (2007). They consider a dynamic model of work, leisure and savings, and find that if consumption and leisure are equally susceptible to consumption externalities then there is no distortion in equilibrium.

The function Φ is increasing in y_i and decreasing in each element of the vector y_{-i}. It is also natural to assume that when all neighbors consume y_i, that is each component of y_{-i} is equal to y_i, then the effect of the neighbors vanishes, i.e. $\Phi(y_i, y_i) = y_i$. Individuals care about their consumption relative to the average consumption of their neighbors but this might be weighted by a term $S(n_i)$ characterizing the size of the neighborhood. These considerations are reflected in the following formulation.

$$\Phi(y_i, y_{-i}) = y_i + \alpha S(n_i) \left[y_i - \frac{1}{n_i} \sum\nolimits_{j \in n_i(g)} y_j \right] \tag{2}$$

Two remarks are in order here. One, $\alpha = 0$ corresponds to the benchmark no externality model. When $\alpha > 0$ individuals are negatively affected by the consumption of their neighbors. By contrast, $\alpha < 0$ corresponds to a positive externality. We will focus on the case $\alpha > 0$, as this appears to capture the idea that individuals are negatively affected by an increase in consumption by neighbors. Two, we discuss the role of $S(n_i)$. If $S(n_i) = n_i$ then the affect of the effect of the size of the neighborhood is linear, while if $S(n_i) = 1$ then only the average consumption of neighbors matters. We focus on these two polar cases as they help us clarify the types of effects at work but we are aware that the intermediate specification with a small size effect is probably more realistic than these polar cases.

Finally, we assume that u_i has the familiar form

$$u_i(x, y) = x^{\sigma} y^{1-\sigma} \tag{3}$$

with $0 < \sigma < 1$.
We will suppose that good x is the numeraire good and that the price of good y is p. A consumer i's optimization program reads

$$\begin{array}{cl} \max_{(x_i, y_i)} & u_i(x_i, y_i, \{y_j\}_{j \in N(i)}) \\ s.t. & x_i + p y_i = \omega_i + p \nu_i \end{array} \tag{4}$$

Let $(\widehat{x}_i, \widehat{y}_i)$ solve this problem.

A general equilibrium is a strictly positive price p and a vector of allocations $(\widehat{x}_i, \widehat{y}_i)_{i\in N}$ such that

1. Markets clear: $\sum_{i\in N} \widehat{x}_i = \sum_{i\in N} \omega_i$, $\sum_{i\in N} \widehat{y}_i = \sum_{i\in N} \nu_i$.
2. For each $i \in N$, $(\widehat{x}_i, \widehat{y}_i)$ solves the optimization problem outlined above.

3 Aggregate neighborhood comparisons

This section studies a scenario in which individuals weight the difference between their own consumption and their neighbors' consumption by the size of their neighborhood. This corresponds to the case $S(n_i) = n_i$ in equation 2.[5] We will first study a model in which all individuals have identical endowments and so the only source of heterogeneity is different locations in a social network. This allows us to isolate the pure effects of social networks. We will then move to a model in which individuals have differing endowments and ask how inequalities in different dimensions jointly shape the market prices and allocations.

We start with some preliminary computations to derive individual and aggregate demands. The first order conditions associated with the optimization problem are

$$\begin{aligned}
0 &= \sigma x_i^{\sigma-1}\left(y_i[1+\alpha n_i] - \alpha\left[\sum_{j\in N(i)} y_j\right]\right)^{1-\sigma} - \lambda \\
0 &= x_i^{\sigma}(1-\sigma)[1+\alpha n_i]\left(y_i[1+\alpha n_i] - \alpha\left[\sum_{j\in N(i)} y_j\right]\right)^{-\sigma} - \lambda p \\
0 &= \omega_i + p\nu_i - x_i - py_i
\end{aligned} \tag{5}$$

For fixed prices, how does a neighbor's consumption of the socially sensitive good affect the marginal returns on own consumption of y? We note from the second line in (5) that for fixed n_i, marginal utility to y_i is clearly increasing in consumption of y by a neighbor. Next we consider the impact of an additional neighbor. It is easily seen that so long as consumption by the new neighbor is equal or larger than current own consumption, the marginal utility from consumption of y_i will increase. But, with a bit of algebra, we can also see that if the consumption of the neighbor is significantly smaller than own consumption and current neighbors consumption then the marginal utility from y_i may actually fall upon the addition of a new neighbor.

[5] Section 4 studies the model where individuals care about their consumption relative to the *average* consumption of their neighbors, $S(n_i) = 1$.

We observe that in our model the first order conditions are necessary for an interior optimum. We will restrict attention to interior solutions of the maximization problem faced by individuals.[6] The demands for goods 1 and 2 are given by:

$$f_i^1(p, \{y_j\}_{j\in N(i)}) = \sigma \left(\omega_i + p\nu_i - \frac{\alpha}{1+\alpha n_i} p \sum_{j\in N(i)} y_j \right) \tag{6}$$

$$f_i^2(p, \{y_j\}_{j\in N(i)}) = \frac{1-\sigma}{p} \left(\omega_i + p\nu_i + \frac{\sigma}{1-\sigma} \frac{\alpha}{1+\alpha n_i} p \sum_{j\in N(i)} y_j \right) \tag{7}$$

We can use equation (7) to obtain for each i:

$$y_i - \frac{\alpha\sigma}{1+\alpha n_i} \sum_{j\in N(i)} y_j - \frac{1-\sigma}{p}(\omega_i + p\nu_i) = 0 \tag{8}$$

This can be rewritten as

$$y_i - \frac{\alpha\sigma}{1+\alpha n_i} G_i \cdot Y - \frac{1-\sigma}{p}(\omega_i + p\nu_i) = 0 \tag{9}$$

where Y is the N-dimensional vector of good 2 consumption, G_i is the ith row of the $N \times N$ matrix of connections, i.e. the adjacency matrix.

The demands y_i for all consumers may be expressed in matrix form as

$$\left[I - \alpha\sigma G^N\right] Y - \frac{1-\sigma}{p} W = 0 \tag{10}$$

where I is the identity matrix and G^N is the $N \times N$ matrix of connections in which every row is normalized so that the sum of the elements add to $\frac{n_i}{1+\alpha n_i}$, and W is the N-dimensional vector of individual wealth.

Whenever $\left[I - \alpha\sigma G^N\right]$ is invertible we can write the demand for good y as:

$$Y = \frac{1-\sigma}{p} \left[I - \alpha\sigma G^N\right]^{-1} W \tag{11}$$

[6] We note that the optimum will be interior if endowments are positive, prices are positive and relative consumption effects are sufficiently small.

3.1 Homogeneous agents

This section deals with a benchmark model where all individuals have identical endowments. Here, with no social interaction, the equilibrium is unique and characterized by no trade and the price is simply given by a ratio of endowments and the relative importance assigned by individual preferences to the two goods. How does social interaction affect equilibrium prices and allocations? Our first finding is that general equilibrium prices can be expressed as a function of the average centrality of the network, and that an individual's consumption is proportional to her network centrality. We then examine the effects of changing networks. We show that adding a link to a network always raises price of the socially sensitive good and a link between i and j alters their equilibrium consumption of the goods in proportion to their centrality in the initial network. We illustrate the quantitative significance of these effects with the help of numerical examples.

Since endowments are identical, the wealth of an agent is given by

$$W_i = \omega_i + p\nu_i = \omega + p\nu \tag{12}$$

which means that

$$W = (\omega + p\nu)J \tag{13}$$

where J is the N-dimensional vector of ones. We can now use equation (11) to obtain:

$$Y = \frac{1-\sigma}{p}\left[I - \alpha\sigma G^N\right]^{-1} J(\omega + p\nu) \tag{14}$$

We now introduce our concept of network centrality.

Definition 1 *Let G^N be the $N \times N$ adjacency matrix in which a row i is normalized by $\frac{1}{1+\alpha n_i}$, where n_i is the degree of agent i. Then we define the centrality vector B by*

$$B = \left[I - \alpha\sigma G^N\right]^{-1} J \tag{15}$$

where J is the N dimensional vector of ones.

When $\alpha\sigma$ is smaller than the inverse of the modulo of the largest eigenvalue of G^N, the inverse $\left[I - \alpha\sigma G^N\right]^{-1}$ can be expressed as a power series

$$\left[I - \alpha\sigma G^N\right]^{-1} = \sum_{s=0}^{\infty} \left(\alpha\sigma G^N\right)^s \tag{16}$$

In our model, observe that the condition for convergence is always met. This is because, from the Perron-Frobinius Theorem we know that an eigen value is less than the maximum sum across all rows. In our case, it can be checked that the maximum across all rows is indeed smaller than 1. By assumption $\alpha\sigma < 1$ and so the series converges. Thus, due to the normalization, implicit in the definition of the matrix G^N, we do not require any assumptions on the magnitude of the local effect. This is is contrast to the to Ballester, Calvo-Armengol and Zenou (2006), where convergence requires that local effects α be sufficiently small.

The element (i, j) of this matrix can be written as

$$\left\{\left[I - \alpha\sigma G^N\right]^{-1}\right\}_{(i,j)} = \sum_{s=0}^{\infty} (\alpha\sigma)^s \{(G^N)^s\}_{(i,j)} \tag{17}$$

where $\{(G^N)^s\}_{(i,j)}$ counts the number of paths starting in j and ending at i of length s, weighted by the factors defined in Definition 1. This expression provides a nice interpretation of centrality in terms of interactions with neighbors of increasing distance. In fact the centrality of an individual B_i reflects the weighted sum of paths of all the different possible lengths.

We now have all the notation and concepts needed to state our first result which characterizes the relation between market equilibrium and social interaction. Let $\overline{B} = \frac{1}{N}\sum_{k=1}^{N} B_k$.

Proposition 1 *There exists an interior equilibrium. In this equilibrium, the allocations of goods for individual i are*

$$x_i = \omega \frac{1 - (1 - \sigma)B_i}{1 - (1 - \sigma)\overline{B}} \tag{18}$$

$$y_i = B_i \frac{1 - \sigma}{p}(\omega + p\nu) = \frac{B_i}{\overline{B}}\nu \tag{19}$$

while the price is given by

$$p = \frac{\omega}{\nu}\left[\frac{1}{1 - \sigma}\frac{1}{\overline{B}} - 1\right]^{-1} \tag{20}$$

Proof: The proof of existence is constructive. From equations (14) and (15) it follows that individual allocations are collinear in B:

$$Y = B\frac{1 - \sigma}{p}(\omega + p\nu) \tag{21}$$

In order to find the price p that equates supply and demand we solve the market clearing equation:

$$\sum_{i=1}^{N} y_i = \frac{1 - \sigma}{p}(\omega + p\nu)\sum_{i=1}^{N} B_i = N\nu \tag{22}$$

so that

$$\frac{1-\sigma}{p}(\omega + p\nu) = \frac{N\nu}{\sum_{k=1}^{N} B_k} \tag{23}$$

Therefore

$$Y = \frac{B}{\sum_{k=1}^{N} B_k} N\nu = \frac{B}{\overline{B}}\nu \tag{24}$$

with $\overline{B} = \frac{1}{N}\sum_{i=1}^{N} B_i$. Equivalently we have

$$y_i = \frac{B_i}{\sum_{k=1}^{N} B_k} N\nu = \frac{B_i}{\overline{B}}\nu \tag{25}$$

Finally, from equation (23) note that the equilibrium price is given by the equation

$$(1-\sigma)\frac{\omega}{p} = \frac{N\nu}{\sum_{i=1}^{N} B_i} - (1-\sigma)\nu \tag{26}$$

leading to

$$p = \frac{\omega}{\nu}\left[\frac{1}{1-\sigma}\frac{N}{\sum_{i=1}^{N} B_i} - 1\right]^{-1} \tag{27}$$

From

$$x_i = \omega + p\nu - py_i \tag{28}$$

we get

$$\begin{aligned} x_i &= \omega + \frac{\omega}{\nu}\left[\frac{1}{1-\sigma}\frac{N}{\sum_{k=1}^{N} B_k} - 1\right]^{-1}\left[\nu - \frac{B_i}{\sum_{k=1}^{N} B_k} N\nu\right] \\ &= \omega\frac{N-(1-\sigma)NB_i}{N-(1-\sigma)\sum_{k=1}^{N} B_k} = \omega\frac{1-(1-\sigma)B_i}{1-(1-\sigma)\overline{B}} \end{aligned} \tag{29}$$

At this stage it is necessary to check that this allocation is indeed an equilibrium. Under our hypothesis on $\alpha\sigma$, $B_i > 0$ and $\overline{B} > 0$. We need to verify that $p > 0, x_i > 0, y_i > 0$ and $y_i(1+\alpha n_i) - \alpha\sum_{j\in N(i)} y_j > 0$ for all i. These inequalities are verified in the Appendix.

■

This result explains how markets and social structures jointly shape prices, allocations and welfare. We observe that networks with higher average centrality will exhibit higher prices for the socially sensitive good. Prices are not affected by the distribution of centralities. This is an aspect of the linear structure of the model. Moreover, equilibrium price is increasing in the importance of the socially sensitive good, which is reflected in the value of $1-\sigma$.

Second, observe that the consumption of socially sensitive good y_i is proportional and increasing in the centrality of agent i. Correspondingly, the consumption of the standard good x decreases with the centrality. We now comment on the relation between degree and consumption. One may expect that a higher degree individual will be led to compare himself with more neighbors and this will push him toward higher consumption of the socially sensitive good. While this is clearly true, it is also the case that the consumption of the neighbors is in turn affected by their degree and so forth. The centrality measure captures this indirect effect of the structure of interaction. These considerations are reflected in the following recursive formulation of the centrality measure:

$$B_k = 1 + \alpha\sigma \frac{1}{1+\alpha n_k} \sum_{j \in N(k)} B_j \tag{30}$$

The consumption y_i of the socially sensitive good by agent i is increasing in the number of direct neighbors and also positively affected by the centrality of these neighbors. We observe that individual consumption of good 1 is larger than initial endowment if and only if centrality is below the average, i.e. $\sum_{k=1}^{N} B_k > NB_i$ or $\frac{1}{N}\sum_{k=1}^{N} B_k > B_i$. The reverse is true for good 2. The intuition is that the more central an agent is, the more she consumes of good 2 in order to cope with the larger negative externality.

We now illustrate the quantitative magnitude of the effect of social structure on equilibrium outcomes. We note that, in our model, the addition or deletion of a neighbor alters the utility function of the individual, making utility comparisons difficult. We will therefore restrict ourselves to comparing utilities of agents whose neighborhood, and hence preferences, remain unchanged.

Example 1 *Social embeddedness and economic outcomes*

In this economy all agents has an endowment of 10 units of either good and $\alpha = \sigma = 0.5$. Figure 1 presents four standard networks: empty, star, ring, and core-periphery. Figure 2 summarizes information on market equilibrium prices, allocations and utilities. We would like to bring out two points: one, social structure has significant effects on prices and allocations. A move from the empty network to the ring raises prices by a 100%, but has no effects on allocations. On the other hand, moving from the ring to the star lowers prices by almost 12% and leads to 16% increase in consumption of the socially sensitive good and a 29% decrease in consumption of standard good by the central agent. Our second point is that social structure has substantial effects on welfare: the utility of the peripheral agents in the star and the core-periphery network (with one neighbor each) are very different.

△

We now illustrate the key role of market interaction in mediating the between social network and individuals.

Example 2 *No man is an island: General equilibrium effects*

In this economy all agents have an endowment of 10 units of either good and $\alpha = \sigma = 0.5$. Figure 3 presents four networks with progressively increasing links but they all share the feature that agent 8 is isolated. Figure 4 summarizes information on market equilibrium prices, allocations and utilities. We would like to bring out two points: one, as the connected part of society gets more densely linked, the price of the socially sensitive good steadily increases while its consumption steadily moves away from the isolated agent and toward the more connected individuals. Two, we observe that the utility of the isolated agent actually increases from 10.44 in the initial network all the way to 11.36 when the core social group constitutes a complete hexagon. △

Changing networks: Our characterization of prices in Proposition 1 tells us prices are an increasing function of average network centrality. Adding links in a network raises paths between agents and this raises average centralities, which in turn raises raises prices. The following result summarizes these ideas.

Proposition 2 *For small α, starting from any network $G \neq G^c$, the addition of a link raises p; it therefore follows that this price is minimized in the empty network and maximized in the complete network.*

Adding links clearly increases number of paths between any two agents, and this pushes towards greater centrality for all individuals. In our setting, it also alters the weights of the paths as the number of neighbors also appears in the denominator of the interaction matrix G^N. This presents some technical problems which complicate the argument significantly and we are obliged to restrict attention to small values of α. The details of the computations are provided in the appendix.

We now examine the nature of the critical link: this is the link which has maximum impact on the price of socially sensitive good. From Proposition 1 and the discussions above, this is the link which increases the sum (or average) of centralities in the network.

Proposition 3 *Fix a network $g \neq g^c$. For sufficiently small α, the critical link g_{ij} is the solution to the following problem:*

$$\max_{ij} \frac{\alpha\sigma}{(1+\alpha(n_i+1))(1+\alpha n_i)} + \frac{\alpha\sigma}{(1+\alpha(n_j+1))(1+\alpha n_j)} \tag{31}$$

This result says that, for instance, in a network g with two or more isolated agents, a critical link would be between a pair of isolated agents. This result is somewhat surprising, as we might expect a link between two highly connected individuals to maximize price effects. The intuition for our result is as follows: the increment to centrality of two connected agents varies inversely with their current degree, due to the normalization involved in the construction of the adjacency matrix G^N. So the marginal impact of a new link is highest for those with the lowest centrality. In our context, with α small, only first order effects are relevant and so a link between agents with lowest current degree maximizes price rise![7]

We now examine how new links affect individual demands. To gain some intuition for the forces at work, consider the case where individuals are located around a circle and a link is added between two individuals i and j. In the initial network all individuals are in a symmetric situation and so the first effect of the additional link is that it increases the marginal return from increasing consumption of good 2 for both i and j. Such an increase in turn leads creates pressure on the demands for good 2 from the neighbors of i and j and the effects may be rather large depending on the centrality of these individuals. However, when α is very small, these second order or indirect social effects on the neighbors of i and j are relatively small and the first order direct effects prevail. The following result summarizes our analysis of the effects of additional links on equilibrium.

Proposition 4 *Suppose a new link is added between two agents i and j. There is an $\hat{\alpha} > 0$ such that for $\alpha < \hat{\alpha}$, there is an increase in the consumption of the socially sensitive good and a decrease in the consumption of the standard good by both i and j. Correspondingly, the consumption of the socially sensitive good decreases while the consumption of the standard good increases, for all agents $h \neq i, j$*

The following example illustrates the effects of an additional link on equilibrium prices and allocations.

Example 3 *The critical link.*

In Figure 5 we illustrate two ways of adding links, in one case we add a link between two central agents, while in the second case we add a link between two spoke agents. We fix $\sigma = 0.5$ and study equilibrium results for moderate and high relative consumption influences, $\alpha = 0.5$ and $\alpha = 0.9$. The results are presented in Figures 6 and

[7] While we have not been able to provide a proof, we believe that this intuition is robust, and that the critical link result generalizes to all values of α. Example 3 below considers the effects of adding links and obtains similar large effects from linking poorly linked individuals, for a range of α values and shows that critical link connects agents with small degrees.

7: we find that adding a link between two spoke agents has a bigger impact on prices as compared to adding link between the hubs.

△

3.2 Wealth heterogeneity

This section extends the model by allowing for heterogeneities in endowments. Our principle result is that heterogeneities in endowments and network centrality are complementary in their effects, i.e., the wealth of an individual affects equilibrium prices and allocations in proportion to her centrality. We exploit this property to show that redistributions of wealth across individuals with different network centralities have significant price and allocation effects. We also find that as a segregated society integrates the poor lose while the rich gain.

Recall that the demand for the socially sensitive good is given by:

$$Y = \frac{1-\sigma}{p}\left[I - \alpha\sigma G^N\right]^{-1} W \tag{32}$$

Let the (column) vector of ω_i be denoted Ω and let Ψ denote the (column) vector of ν_i. Then, we have

$$W = \Omega + p\Psi \tag{33}$$

We note that if $M = \left[I - \alpha\sigma G^N\right]^{-1}$ then we get

$$\begin{aligned} Y &= \frac{1-\sigma}{p} M(\Omega + p\Psi) && (34)\\ &= \frac{1-\sigma}{p} M\Omega + (1-\sigma)M\Psi && (35) \end{aligned}$$

Note that $M\Omega$ is the network centrality weighted by the endowments of good ω and we shall refer to it as $\omega-$ centrality and denote it by B_ω. Similarly $M\Psi$ is the $\nu-$centrality and we denote it by B_ν. Note that we recover the homogeneous case by setting $M\Omega = MJ\omega = B\omega$ and $M\Psi = MJ\nu = B\nu$ where B is as in Definition 1 above. The equilibrium price vector can be obtained from the market clearing condition

$$\sum_{i=1}^{N} y_i = \sum_{i=1}^{N} \nu_i \Longleftrightarrow Y'J = \Psi'J \tag{36}$$

We get

$$\begin{aligned} \Psi'J &= \frac{1-\sigma}{p}\left[M(\Omega + p\Psi)\right]' J \\ &= \frac{1-\sigma}{p}\left[M\Omega\right]' J + (1-\sigma)\left[M\Psi\right]' J \end{aligned}$$

so that

$$p = \frac{(1-\sigma)\,[M\Omega]'\,J}{\Psi' J - (1-\sigma)\,[M\Psi]'\,J} \tag{37}$$

Finally, the equilibrium allocation of the socially sensitive good is

$$Y = \frac{\Psi' J - (1-\sigma)\,[M\Psi]'\,J}{[M\Omega]'\,J} M\Omega + (1-\sigma) M\Psi \tag{38}$$

while the allocation in the non-socially sensitive good can be obtained from

$$X = W - pY \tag{39}$$

Let R_ν denote the total endowment of the socially sensitive good and let R_ω denote the total endowment of the other good. We summarize our discussion in the following result.

Proposition 5 *In an interior equilibrium the allocation of individual i is given by:*[8]

$$y_i = \frac{R_\nu - (1-\sigma)\sum_{i\in N} B_{\nu,i}}{\sum_{i\in N} B_{\omega,i}} B_{\omega,i} + (1-\sigma) B_{\nu,i}. \tag{40}$$

$$x_i = \omega_i + \frac{(1-\sigma)B'_\omega J}{R_\nu - (1-\sigma)B'_\nu J} v_i) - \frac{(1-\sigma)B'_\omega J}{R_\nu - (1-\sigma)^2 B'_\nu J}[B_{v,i} + B_{w,i}) \tag{41}$$

Furthermore, the equilibrium price is given by

$$p = \frac{(1-\sigma)B'_\omega J}{R_\nu - (1-\sigma)B'_\nu J} \tag{42}$$

The sum of $\omega-$centralities can be expressed as $\sum_i \sum_j M_{ij}\omega_j$. The above result says that the price of the socially sensitive good is increasing in the sum of $\omega-$centralities. This increase may be caused by an increase in endowments or an increase in the network centrality per se. An increase in endowment of the standard good raises incomes and leads to an increase in demand for the socially sensitive good. The price of the socially sensitive good has to increase to offset this increased demand. Similarly, keeping endowments of the standard good fixed, an increase in centralities of agents increases demand for the socially sensitive good and this necessitates an increase in equilibrium prices (as endowments are constant). The effects of changes in $\nu-$ centrality are more complicated. It can be checked that an increase in $\nu-$ centralities caused by pure network changes will raise the price of the socially sensitive good. However, an increase in endowment of some agents will lower price. The magnitude of this effect on price will depend on the centrality of the agents whose

[8] As in the basic model, the inverse of the adjacency matrix is well defined; an equilibrium exists when the 'net' consumption of the socially sensitive good and prices are positive.

endowments have been altered: in particular, the fall in price is smaller the larger the centrality of the agents who are given more endowments. Similarly, we observe that the equilibrium allocations are related to the weighted centralities of agents. In particular, the consumption of the socially sensitive good is increasing in the ω-centrality as well as the ν-centrality of an agent, while the converse is true for the equilibrium allocation of the standard good, *ceteris paribus*.

We next consider the effect of redistributions in endowments. In our model, with *no* consumption externalities a redistribution leaves the price unchanged. We can deduce this from the formula for prices in Proposition 5 and noting that B_w and B_v will simply be equal to the aggregate endowments of these two goods, respectively, when $\alpha = 0$. When $\alpha > 0$, social interaction has significant effects on prices: a transfer from a less central to a more central agent will raise prices, the transfer in the reverse direction will lower prices. It is useful to define $\tilde{M}_i = \sum_j M_{ji}$, as the weighted sum of paths from all agents to agent i. The following result summarizes these observations regarding the effects of a redistribution in endowments.

Proposition 6 *Suppose $\tilde{M}_q > \tilde{M}_{q'}$. The price of a socially sensitive good is increasing in transfers from agent q' to q and decreasing in transfers from q to q'. There are no price effects of a transfer from q' to q, if $\tilde{M}_q = \tilde{M}_{q'}$.*

Proof: Recall from equation (42) that prices are given by

$$p = \frac{(1-\sigma)B'_{\omega}J}{R_{\nu} - (1-\sigma)B'_{\nu}J} \tag{43}$$

where $B'_{\omega}J = \sum_{i=1}^{N}\sum_{j=1}^{N} M_{ij}\omega_j$, and $B'_{\nu}J = \sum_{i=1}^{N}\sum_{j=1}^{N} M_{ij}\nu_j$. Let us consider a transfer Δ of the socially sensitive good y from q' to q. We will focus on the term $B'_{\nu}J$, as all other terms remain unchanged.

Define initial endowment distribution as (ω, ν), and the new endowment distribution as (ω, ν'). Note that $\nu_i = \nu'_i$ for all agents except q and q', where $\nu'_q = \nu_q + \Delta$ while $\nu'_{q'} = \nu_{q'} - \Delta$. $B'_{\nu}J$ can be written as:

$$\sum_{i=1}^{N}\sum_{j=1}^{N} M_{ij}\nu_j = \sum_{i\neq q,q'}\sum_{j\neq q,q'} M_{ij}\nu_j + \sum_{j} M_{qj}\nu_j + \sum_{j} M_{q'j}\nu_j + \sum_{i\neq q,q'} M_{iq}\nu_i + \sum_{i\neq q,q'} M_{iq'}\nu_i \tag{44}$$

In the same way, we can write the post transfer weighted centrality $B'_{\nu'}J$ as:

$$\sum_{i=1}^{N}\sum_{j=1}^{N} M_{ij}\nu'_j = \sum_{i\neq q,q'}\sum_{j\neq q,q'} M_{ij}\nu'_j + \sum_{j} M_{qj}\nu'_j + \sum_{j} M_{q'j}\nu'_j + \sum_{i\neq q,q'} M_{iq}\nu'_q + \sum_{i\neq q,q'} M_{iq'}\nu'_{q'} \tag{45}$$

However, note that $\nu_i = \nu'_i$, for all $i \neq q, q'$. So we can rewrite (45) as follows:

$$\begin{aligned}\sum\nolimits_{i=1}^{N}\sum\nolimits_{j=1}^{N} M_{ij}\nu'_j \;=\; & \sum_{i\neq q,q'}\sum_{j\neq q,q'} M_{ij}\nu_j + \sum_{j\neq q,q'} M_{qj}\nu_j + M_{qq}\nu'_q + M_{qq'}\nu'_{q'} + \\ & \sum_{j\neq q,q'} M_{q'j}\nu_j + M_{q'q'}\nu'_{q'} + M_{qq'}\nu'_q + \sum_{i\neq q,q'} M_{iq}\nu'_q + \sum_{i\neq q,q'} M_{iq'}\nu'_q \end{aligned} \quad (46)$$

Comparing equations (44) and 46, we infer that $B'_{\nu'}J > B'_{\nu}J$ if and only if

$$\begin{aligned} & M_{qq}\nu'_q + M_{qq'}\nu'_{q'} + M_{q'q}\nu'_q + M_{q'q'}\nu'_{q'} + \sum_{i\neq q,q'} M_{iq}\nu'_q + \sum_{i\neq q,q'} M_{iq'}\nu'_q \\ > \; & M_{qq}\nu_q + M_{qq'}\nu_{q'} + M_{q'q}\nu_q + M_{q'q'}\nu_{q'} + \sum_{i\neq q,q'} M_{iq}\nu_q + \sum_{i\neq q,q'} M_{iq'}\nu_{q'} \end{aligned} \quad (47)$$

This inequality holds if and only if $\tilde{M}_q = \sum_i M_{iq} > \sum_i M_{iq'} = \tilde{M}_{q'}$. The argument for transfer of good x is analogous and omitted.

■

Equation 42 actually says that the price effect of a resource transfer is proportional to x. An examination of arguments in the proof of Proposition 6 then tells us that change in prices is proportional to the difference in centrality of the agents involved, i.e., $\tilde{M}_q - \tilde{M}_{q'}$. Wealth and network inequality thus reinforce each other in their effect on price.

The next example illustrates this complementarity and also brings out the effects of new links.

Example 4 *Changing networks in unequal societies*

Let $\alpha = 0.5$ and $\sigma = 0.5$. We suppose that the network consists of two distinct components, each with 4 agents forming a star. There are 2 rich agents and 6 poor agents. Figure 8 presents the case when rich agents occupy the hub nodes, while Figure 9 presents the results for the case where the poor agents occupy the central nodes. These computations show: One, prices are higher when rich agents are in the center of the network and occupy hub positions. Two, creating a new link between the two components raises the price irrespective of the location of the link and the rich agents. △

A recurring theme in the literature on happiness and relative consumption concerns has been the role of changing social comparisons; see e.g., Layard (2004). The general argument is that, over time, incomes have grown but due to social changes middle class and poor individuals are more aware of the life styles of the richer classes. This greater awareness has altered consumption patterns of the poor and the middle class, as well as affected utility adversely. The following example addresses this argument.

Example 5 *Integrated and segregated societies.*

Let $\alpha = 0.5$ and $\sigma = 0.5$. Again we consider a network with two distinct components, each with 4 agents. These networks are given in Figure 10. There are 4 rich agent with endowments of 10 units of the standard good and 2 units of the socially sensitive good. The 4 poor agents have 5 units and 1 unit of the two goods, respectively. We consider two types of societies, segregated (the poor and rich live in different components) and integrated (the rich and poor live are mixed in the same component). The results are reported in Figure 11. We find that utility of the poor agents is significantly lower in integrated communities as compared to segregated communities; the converse is true for rich agents!

$\triangle$

The previous example shows how changing neighbors – or changes in observation of consumption patterns – have interesting and powerful effects on utility levels: substituting a poor neighbor by a rich neighbor unambiguously lowers utility. The intuition is simple: a richer neighbor consumes more of good y and, due to relative consumption concerns, this lowers utility.[9]

We conclude by noting an implication of our analysis: our examples suggest that rich agents will desire links with the poor, who will in turn try and avoid the rich! In a world where link formation requires consent on the part of both agents, this suggests that a society segregated by economic class may well be stable.[10]

4 Neighborhood averages

We now study the case where individuals care about their consumption relative to the average consumption of their neighbors. In our model this corresponds to the case $S(n_i) = 1$ in equation 2. Recall, that the utility function reads as:

$$u(x_i, y_i, \{y_j\}_{j \in N(i)}) = x_i^{\sigma} \left(y_i + \alpha \left[y_i - \frac{1}{n_i} \sum\nolimits_{j \in n_i(g)} y_j \right] \right)^{1-\sigma} \tag{48}$$

The first order conditions associated with the individual optimization problem are:

[9]In Example 5, prices remain unchanged as we move from segregated to integrated societies. This turns out to be true, in general, for societies where everyone has the same number of neighbors. The appendix states a proves a result along these lines.

[10]For an interesting recent treatment of endogenous groups in a model of social interactions, see Zanella (2007).

$$
\begin{aligned}
0 &= \sigma x_i^{\sigma-1}\left(y_i(1+\alpha)-\alpha\left[\frac{1}{n_i}\sum_{j\in N(i)} y_j\right]\right)^{1-\sigma}-\lambda \\
0 &= x_i^{\sigma}(1-\sigma)[1+\alpha]\left(y_i[1+\alpha]-\alpha\left[\frac{1}{n_i}\sum_{j\in N(i)} y_j\right]\right)^{-\sigma}-\lambda p \\
0 &= \omega_i+p\nu_i-x_i-py_i
\end{aligned} \tag{49}
$$

It is interesting to examine how does a neighbor's consumption of the socially sensitive good affect the marginal returns on own consumption of y? We note from the second line in (49) that for fixed n_i, marginal utility to y_i is clearly increasing in consumption of y by a neighbor. We observe that this effect is analogous to the effect in the earlier formulation where size of neighborhood matters; refer to discussion after equation (5). Next consider the impact of an additional neighbor. A new neighbor raises the marginal returns from consuming y if and only if the consumption of good y by this new neighbor is higher than the average of the existing neighbors. We emphasize that this effect is independent of the current consumption of the concerned individual; thus the effects of adding neighbors in the present model may be quite different from the model with aggregate neighbors consumption.

We turn next to the derivation of aggregate demand and equilibrium prices. Let us start by observing that in our model the first order conditions are necessary for an interior optimum. In this paper, we will restrict attention to interior solutions of the maximization problem faced by individuals. The demands for goods 1 and 2 are given by:

$$f_i^1(p,\{y_j\}_{j\in N(i)})=\sigma\left(\omega_i+p\nu_i-\frac{\alpha}{1+\alpha}p\frac{1}{n_i}\sum_{j\in N(i)} y_j\right) \tag{50}$$

$$f_i^2(p,\{y_j\}_{j\in N(i)})=\frac{1-\sigma}{p}\left(\omega_i+p\nu_i+\frac{\sigma}{1-\sigma}\frac{\alpha}{1+\alpha}p\frac{1}{n_i}\sum_{j\in N(i)} y_j\right) \tag{51}$$

We can use equation (7) to obtain for each i:

$$y_i-\frac{\alpha\sigma}{1+\alpha}\frac{1}{n_i}\sum_{j\in N(i)} y_j-\frac{1-\sigma}{p}(\omega_i+p\nu_i)=0 \tag{52}$$

This can be rewritten as

$$y_i-\frac{\alpha\sigma}{1+\alpha}\frac{1}{n_i}G_i\cdot Y-\frac{1-\sigma}{p}(\omega_i+p\nu_i)=0 \tag{53}$$

where Y is the N-dimensional vector of good 2 consumption, G_i is the ith row of the $N \times N$ matrix of connections, i.e. the adjacency matrix.

The demands y_i for all consumers may be expressed in matrix form as

$$\left[I - \alpha\sigma\hat{G}\right] Y - \frac{1-\sigma}{p} W = 0 \tag{54}$$

where I is the identity matrix and $\hat{G}$ is the $N \times N$ matrix of connections in which every row is normalized so that the sum of the elements add to $\frac{1}{1+\alpha}$ and W is the N-dimensional vector of individual wealth.

If we note $\hat{M} = \left[I - \alpha\sigma\hat{G}\right]^{-1}$ then, as in the previous section, we can write the demand for good y as:

$$\begin{aligned} Y &= \frac{1-\sigma}{p}\hat{M}(\Omega + p\Psi) && (55) \\ &= \frac{1-\sigma}{p}\hat{M}\Omega + (1-\sigma)\hat{M}\Psi && (56) \end{aligned}$$

Note that $\hat{M}\Omega$ is the network centrality weighted by the endowments of good ω and we shall refer to it as $\omega-$ centrality and denote it by $\hat{B}_\omega$. Similarly $\hat{M}\Psi$ is the $\nu-$centrality and we denote it by $\hat{B}_\nu$. We now equate market demand with aggregate endowments and solve for price equilibrium and then substitute these prices in demand for goods to get the equilibrium prices and allocations, exactly as in the proof of Proposition 5.

Proposition 7 *Let $\alpha\sigma$ be smaller than the inverse of the modulo of the largest eigenvalue of $\hat{G}$. In an interior equilibrium the allocation of individual i is given by:*[11]

$$y_i = \frac{R_\nu - (1-\sigma)\sum_{i\in N}\hat{B}_{\nu,i}}{\sum_{i\in N}\hat{B}_{\omega,i}}\hat{B}_{\omega,i} + (1-\sigma)\hat{B}_{\nu,i}. \tag{57}$$

$$x_i = \omega_i + \frac{(1-\sigma)\hat{B}'_\omega J}{R_\nu - (1-\sigma)\hat{B}'_\nu J} v_i) - \frac{(1-\sigma)\hat{B}'_\omega J}{R_\nu - (1-\sigma)^2\hat{B}'_\nu J}[\hat{B}_{v,i} + \hat{B}_{w,i}) \tag{58}$$

Furthermore, the equilibrium price is given by

$$p = \frac{(1-\sigma)\hat{B}'_\omega J}{R_\nu - (1-\sigma)\hat{B}'_\nu J} \tag{59}$$

[11] We can show that the price and allocations stated in this proposition indeed constitute an equilibrium, using arguments along the lines of Proposition 1.

We consider an important special case of the model in which agents have identical endowments: in this case $\omega_i = \omega$ and $\nu_i = \nu$. If everyone chooses the same bundle then everyone faces the same 'neighborhood' and the effect of the local interaction is independent of the number of neighbors a person has. Indeed, if we substitute identical endowments in $\hat{B}_\omega J$ and $\hat{B}_\nu J$ and, after some simple computations, we find that the network component simply drops out and the price is simply a function of aggregate endowments of the two goods. In other words, network centrality plays no role in shaping prices and allocations! This highlights an important difference between the effects of social comparisons based on aggregate neighborhood consumption and those based on neighborhood averages.

However, matters are much more interesting when individuals have different endowments. Now network position comes into play and has an impact on the equilibrium prices and allocations. To get some intuition for this, consider a society with one rich person and $n-1$ poor people. Suppose the network is a star and compare two possible scenarios: one in which a rich agent is the center and the other in which a poor agent is the center. Notice that a rich person faced with a certain average will consume more of good y and thus will create more pressure as compared to a poor person at the center. The general formula for equilibrium prices and allocations in Proposition 7 above illustrates this effects.

The following example clarifies the quantitative effects of network and wealth heterogeneities when people care about the average consumption of their neighbors.

Example 6 *Rich and poor hubs*

Let $\alpha = 0.5$ and $\sigma = 0.5$. We suppose that the network is a star with 8 individuals and 1 is the hub. Seven agents have identical endowments (1,1), while one agent has endowments (5,1). We consider two cases; one, in which the rich individual is the hub, and two, in which the rich individual is a spoke. The results are reported in Figure 7. We find that equilibrium price and allocation effects are substantial. In the case of a rich central agent equilibrium price is higher by approximately 30%. Wealth differences are reinforced by inequality in network centrality, so that poor agents have a much lower utility when the rich agent is central.
Interestingly, the rich agent also prefers to be peripheral in this network. In other words, the outcome with periphery rich agent Pareto dominates the outcome with the hub rich agent! Why is this? First observe that a rich person faces the same average neighborhood. So the difference in outcome arises from two facts, one, the neighbor – the poor central player– faces a lower average wealth neighborhood and two, all other agents no longer struggle to compete with the rich agent. So the price of good y is much lower in the poor hub society as compared to the price in the rich hub society. This allows the rich agent – and all other agents – to have a better balance in consumption!!

△

The above example yields an interesting insight: in a society where people care about their neighbor's consumptions, moving a rich person from a peripheral position to a central position in the social network can actually lower the welfare of *everyone*. The argument above clarifies that this is a consequence of social comparisons and the resulting changes in markets prices. This example highlights an interesting economic phenomenon and also brings out the value of studying social interaction and markets within a common framework.

We turn next to the effects of endowment transfers. Define $\hat{M}_q = \sum_j \hat{M}_{ji}$ as the weighted sum of all paths from all agents j to agent i. The following result, which is analogous to Proposition 6 in section 3.2, summarizes our analysis.

Proposition 8 *Suppose $\hat{M}_q > \hat{M}_{q'}$. The price of the socially sensitive good is increasing in transfers from agent q' to q and decreasing in transfers from q to q'. There are no price effects of a transfer from q' to q, if $\hat{M}_q = \hat{M}_{q'}$.*

Proof: We note that $\hat{M}_q$ is defined with respect to the matrix $\hat{G}$. Once we have defined $\hat{M}$ in this way, the rest of the proof now follows exactly as the proof of proposition 6. ■

Example 7 *Changing networks: a new connection*

Let $\alpha = 0.5$ and $\sigma = 0.5$. We suppose that the network consists of two distinct components, each with 4 agents forming a star. There are two rich agents and six poor agents. Figure 7 presents results when rich agents occupy the hub nodes, while Figure 7 presents results when poor agents occupy the central nodes. First, we observe that in the rich agents at the center society, a new link between the two hubs raises price of good y, but a new link between two spokes actually lowers prices (Figure 7). On the other hand, in the society with rich agents at the periphery, a new link between two spokes raises prices while a new link between the hub agents actually lowers prices! The intuition for this is as follows: in the former society, when we add a link between two hubs, the average consumption of socially sensitive good y by the neighbors of the hubs increases. This pushes up demand of this good and its price rises to accommodate this pressure. By contrast, when a new link is created between two peripheral agents who are poor, they observe a fall in the average consumption of good y of their neighbors. This lowers their demand for good y which in turn is reflected in a lower price of good y in equilibrium.

△

This example allows us to bring out an important difference between the basic model where individuals care about aggregate consumption of neighbors and the present model: recall that in Proposition 2 and in example 4 we showed that prices increase irrespective of location of link and rich agents. By contrast, as example 7 demonstrates, in the averages model a new link raises prices when it connects rich agents but lowers prices when it connects poor agents.

We conclude this section with an example which considers individual well being in segregated and integrated societies.

Example 8 *Integrated and segregated societies.*

Let $\alpha = 0.5$ and $\sigma = 0.5$. Again we consider a network with two distinct components, each with 4 agents as in example 5; these networks are given Figure 10. There are 4 rich agents with endowments of 10 units of the standard good and 2 units of the socially sensitive good. The 4 poor agents have 5 units and 1 unit of the two goods, respectively. We consider two types of societies, segregated and integrated. The results are reported in Figure 7. We find that poor agents are significantly worse off in an integrated society as compared to a segregated one; the converse is true for rich agents! This is in line with our finding of the effects of integration in our basic model.

$\triangle$

The effects are similar to the effects of integration in the basic model with aggregate comparisons.

5 Concluding remarks

Relative consumption concerns appear to be important in day to day life and economists have been studying them for at least a hundred years, following the work of Veblen (1989). This interest has spawned a large theoretical literature which examines the implications of relative consumption concerns; for the most part, this work assumes that individuals care about their own consumption as well as the average consumption of society at large.

Introspection as well as recent empirical work suggest that we care about the relative consumption of those *close to us*, i.e., our neighbors, friends, relatives, acquaintances and colleagues. These considerations lead us to develop a model which incorporates local social comparisons within standard pure exchange model. Our goal has been to understand how the structure of social comparisons and market interaction jointly shape economic exchange and well being.

Our analysis yields three insights: one, equilibrium prices and consumptions are a function of a single network statistic: centrality. Specifically, prices are proportional to sum of centralities, while an individual's consumption depends on how central

she is relative to others in the network.Two, we find that inequalities in wealth and connections reinforce each other in markets: a transfer of resources from less to more central agents raises prices. Three, as segregated communities become integrated the poor lose while the rich gain in utility!
We have assumed that neighbors consumption negatively affects a person's utility. While we believe this is a natural and important case, it would be interesting to also consider the model where neighbors consumptions actually increase individual utility. We have focused on the case of pure exchange and the impact of social comparisons on production and the work leisure trade-off is clearly worth studying. Finally, we have taken the social network to be given: it seems to us that a defining characteristic of modern societies is that individuals have the freedom to choose their neighbors. In future work we hope to explore these ideas.

6 Appendix

Proof of Proposition 1: (the verification of inequalities) Consider an arbitrary coordinate k

$$\begin{aligned}
B_k &= 1+\alpha\sigma\{G^N J\}_k + \alpha^2\sigma^2\{(G^N)^2 J\}_k + \alpha^3\sigma^3\{(G^N)^3 J\}_k + ... \\
&= 1+\alpha\sigma\sum_{h=1}^N g_{kh}^N + \alpha^2\sigma^2\sum_{q=1}^N\sum_{p=1}^N g_{kp}^N g_{pq}^N + \\
&\alpha^3\sigma^3\sum_{q=1}^N\sum_{p=1}^N\sum_{h=1}^N g_{kp}^N g_{ph}^N g_{hq}^N + ... \\
&= 1+\alpha\sigma\sum_{j\in N(k)}\frac{1}{1+\alpha n_k} + \alpha^2\sigma^2\sum_{p=1}^N g_{kp}^N\sum_{q=1}^N g_{pq}^N + \\
&+\alpha^3\sigma^3\sum_{p=1}^N g_{kp}^N\sum_{h=1}^N g_{ph}^N\sum_{q=1}^N g_{hq}^N + ... \\
&= 1+\alpha\sigma\frac{n_k}{1+\alpha n_k} + \alpha^2\sigma^2\sum_{p=1}^N g_{kp}^N\frac{n_p}{1+\alpha n_p} + \\
&+\alpha^3\sigma^3\sum_{p=1}^N g_{kp}^N\sum_{h=1}^N g_{ph}^N\frac{n_h}{1+\alpha n_h} + ... \\
&= 1+\alpha\sigma\frac{n_k}{1+\alpha n_k} + \alpha^2\sigma^2\frac{1}{1+\alpha n_k}\sum_{p\in N(k)}\frac{n_p}{1+\alpha n_p} + \\
&+\alpha^3\sigma^3\frac{1}{1+\alpha n_k}\sum_{p\in N(k)}\frac{1}{1+\alpha n_p}\sum_{h\in N(p)}\frac{n_h}{1+\alpha n_h} + ... \qquad (60)
\end{aligned}$$

The first term is the degree n_k of the agent k scaled down by $1+\alpha n_k$. The quantity $\frac{\alpha n_k}{1+\alpha n_k}$ is increasing in n_k and bounded by 0 and 1. The second term is the sum over the neighbours $N(k)$ of the degrees of the neighbours (also scaled down). This decomposition also allows to define B recursively

$$B_k = 1+\alpha\sigma\frac{1}{1+\alpha n_k}\sum_{j\in N(k)} B_j \qquad (61)$$

Now, from the series decomposition and since $\frac{\alpha n_k}{1+\alpha n_k} < 1$, we have that

$$B_k < 1 + \left[\sum_{s=1}^{\infty} \sigma^s\right] = 1 + \frac{\sigma}{1-\sigma} \tag{62}$$

We then get the bounds

$$1 < B_k < \frac{1}{1-\sigma} \tag{63}$$

The condition for the price to be positive is

$$\frac{1}{1-\sigma}\frac{N}{\sum_{i=1}^{N} B_i} > 1 \tag{64}$$

which clearly holds since $\frac{1}{1-\sigma} > B_i$ for all i. The condition $x_i > 0$ is satisfied as both $(1-\sigma)B_i < 1$ and $(1-\sigma)\overline{B} < 1$ hold. The condition $y_i > 0$ is automatically satisfied as $B_k > 1$. Finally, we consider the condition $y_i(1+\alpha n_i) - \alpha \sum_{j \in N(i)} y_j > 0$ which may be rewritten as

$$y_i - \alpha \frac{1}{(1+\alpha n_i)} \sum_{j \in N(i)} y_j > 0 \tag{65}$$

or

$$B_i - \alpha \frac{1}{(1+\alpha n_i)} \sum_{j \in N(i)} B_j > 0 \tag{66}$$

Using the recursive formulation for B, we see that the condition indeed holds

$$\begin{aligned}
& 1 + \alpha\sigma \frac{1}{1+\alpha n_i} \sum_{j \in N(i)} B_j - \alpha \frac{1}{(1+\alpha n_i)} \sum_{j \in N(i)} B_j && (67)\\
= \quad & 1 - (1-\sigma) \frac{\alpha}{1+\alpha n_i} \sum_{j \in N(i)} B_j && (68)\\
> \quad & 1 - (1-\sigma) \frac{\alpha n_i}{1+\alpha n_i} \frac{1}{1-\sigma} && (69)\\
> \quad & 1 - 1 && (70)\\
> \quad & 0 && (71)
\end{aligned}$$

■

Proof of Proposition 2: If a link is added between i and j, the matrix G is modified to $\widetilde{G} = G + \Delta_{ij} + \Delta_{ji}$ where Δ_{ij} is the matrix defined by $\Delta_{ij} = \{t_{pq}\}_{p,q=1}^{N}$ with $t_{ij} = 1$ and $t_{pq} = 0$ otherwise. In order to evaluate how the vector B is modified by the addition of the link it is useful to note that

$$G^N = \left(G^T \Lambda\right)^T \tag{72}$$

where $(.)^T$ means transpose and Λ is defined as

$$\Lambda = \begin{bmatrix} \frac{1}{1+\alpha n_1} & 0 & 0 & 0 \\ 0 & \frac{1}{1+\alpha n_2} & 0 & 0 \\ 0 & 0 & ... & 0 \\ 0 & 0 & 0 & \frac{1}{1+\alpha n_n} \end{bmatrix} \tag{73}$$

Then the addition of a link between i and j implies that G^N becomes $\widetilde{G}^N$ and

$$\begin{aligned} \widetilde{G}^N &= \left(\widetilde{G}^T \widetilde{\Lambda}\right)^T \\ &= \left((G + \Delta_{ij} + \Delta_{ji})^T \widetilde{\Lambda}\right)^T \end{aligned}$$

with $\widetilde{\Lambda}$ defined as Λ but with the elements at position i and j modified to become $\frac{1}{1+\alpha(n_i+1)}$ and $\frac{1}{1+\alpha(n_j+1)}$.

Therefore, introducing a link between i and j modifies B as follows

$$\widetilde{B} = \left[\sum_{s=0}^{\infty} \alpha^s \sigma^s (\widetilde{G}^N)^s\right] J \tag{74}$$

$$= \left[\sum_{s=0}^{\infty} \alpha^s \sigma^s \left[\left((G + \Delta_{ij} + \Delta_{ji})^T \widetilde{\Lambda}\right)^T\right]^s\right] J \tag{75}$$

Clearly, introducing a connection between i and j affects the value of all the elements of the vector B. However, this effect is vanishing with the distance and as $\alpha\sigma \longrightarrow 0$. It is then useful to look at the first terms in the expression for B noting that all terms are positive. We consider an arbitrary coordinate k. We get for the first three terms

$$\begin{aligned} B_k &= 1 + \alpha\sigma \frac{n_k}{1+\alpha n_k} + \alpha^2\sigma^2 \sum\nolimits_{p=1}^{N} g_{kp}^N \frac{n_p}{1+\alpha n_p} + \\ &\quad + \alpha^3\sigma^3 \sum\nolimits_{p=1}^{N} g_{kp}^N \sum\nolimits_{h=1}^{N} g_{ph}^N \frac{n_h}{1+\alpha n_h} + ... \\ &= 1 + \alpha\sigma \frac{n_k}{1+\alpha n_k} + \alpha^2\sigma^2 \frac{1}{1+\alpha n_k} \sum\nolimits_{p\in N(k)} \frac{n_p}{1+\alpha n_p} + \\ &\quad + \alpha^3\sigma^3 \frac{1}{1+\alpha n_k} \sum\nolimits_{p\in N(k)} \frac{1}{1+\alpha n_p} \sum\nolimits_{h\in N(p)} \frac{n_h}{1+\alpha n_h} + ... \end{aligned} \tag{76}$$

The expansion for B_k allows us to evaluate the effect of the introduction of a link between i and j. Denote this change as ΔB_k. Using the series expansion we then define $\Delta B_k = \sum_{s=1}^{\infty} \Delta B_k^s$ where the suffix indicates the power of $\alpha\sigma$. For the first term in the series we have

$$\begin{aligned}\Delta B_i^1 &= \alpha\sigma\left[\frac{n_i+1}{1+\alpha\{n_i+1\}} - \frac{n_i}{1+\alpha n_i}\right]\\ &= \frac{\alpha\sigma}{[1+\alpha\{n_i+1\}]\,[1+\alpha n_i]}\end{aligned} \tag{77}$$

The second order term ΔB_i^2 is

$$\begin{aligned}\Delta B_i^2 &= \alpha^2\sigma^2\frac{1}{1+\alpha(n_i+1)}\left[\sum\nolimits_{p\in N(i)}\frac{n_p}{1+\alpha n_p}+\frac{n_j+1}{1+\alpha n_j+1}\right]\\ &\quad -\alpha^2\sigma^2\frac{1}{1+\alpha n_i}\sum\nolimits_{p\in N(i)}\frac{n_p}{1+\alpha n_p}\\ &= \alpha^2\sigma^2\left[\frac{1}{1+\alpha(n_i+1)}-\frac{1}{1+\alpha n_i}\right]\sum\nolimits_{p\in N(i)}\frac{n_p}{1+\alpha n_p}\\ &\quad +\alpha^2\sigma^2\frac{1}{1+\alpha(n_i+1)}\frac{n_j+1}{1+\alpha n_j+1}\\ &= \alpha^2\sigma^2\frac{-\alpha}{(1+\alpha(n_i+1))\,(1+\alpha n_i)}\sum\nolimits_{p\in N(i)}\frac{n_p}{1+\alpha n_p}\\ &\quad +\alpha^2\sigma^2\frac{1}{1+\alpha(n_i+1)}\frac{n_j+1}{1+\alpha n_j+1}\\ &= \alpha\sigma^2\frac{1}{1+\alpha(n_i+1)}\left[\frac{\alpha n_j+1}{1+\alpha n_j+1}-\frac{\alpha}{1+\alpha n_i}\sum\nolimits_{p\in N(i)}\frac{\alpha n_p}{1+\alpha n_p}\right]\end{aligned} \tag{78}$$

Consider now how the centralities of the neighbours of i and j are affected. Denote by h a generical neighbour of i, i.e. $h\in N(i), h\neq i,j$. Then, the addition of a link between agent i and j has no effect on n_h so that $\Delta B_h^1=0$. The second term in the expression of B_h is $\alpha^2\sigma^2\frac{1}{1+\alpha n_h}\sum_{p\in N(h)}\frac{n_p}{1+\alpha n_p}$ so that

$$\begin{aligned}\Delta B_h^2 &= \alpha^2\sigma^2\frac{1}{1+\alpha n_h}\left[\frac{n_i+1}{1+\alpha(n_i+1)}+\sum\nolimits_{\substack{p\in N(h)\\ p\neq i}}\frac{n_p}{1+\alpha n_p}\right]\\ &\quad -\alpha^2\sigma^2\frac{1}{1+\alpha n_h}\left[\frac{n_i}{1+\alpha n_i}+\sum\nolimits_{\substack{p\in N(h)\\ p\neq i}}\frac{n_p}{1+\alpha n_p}\right]\\ &= \alpha^2\sigma^2\frac{1}{1+\alpha n_h}\left[\frac{n_i+1}{1+\alpha(n_i+1)}-\frac{n_i}{1+\alpha n_i}\right]\\ &= \alpha^2\sigma^2\frac{1}{1+\alpha n_h}\frac{1}{(1+\alpha(n_i+1))\,(1+\alpha n_i)}\end{aligned} \tag{79}$$

For further neighbours, only higher order terms in $\alpha\sigma$ are non-zero.

We are in a position to evaluate how $\sum_{k=1}^{N}B_k$ is affected by the new link. Let $\sum_{k=1}^{N}\widetilde{B}_k$ be the value of the sum after the new link is introduced. If we keep only the first two terms of the expansion we have:

$$\begin{aligned}\Delta \sum_{k=1}^{N} B_k &= \sum_{k=1}^{N} \widetilde{B}_k - \sum_{k=1}^{N} B_k \\ &\simeq \Delta B_i^1 + \Delta B_i^2 + \Delta B_j^1 + \Delta B_j^2 + \sum_{k \in N(i)} \Delta B_k^2 + \sum_{k \in N(j)} \Delta B_k^2 \end{aligned} \tag{80}$$

Now,

$$\begin{aligned}\Delta B_i^1 + \Delta B_j^1 &\simeq \alpha\sigma \left[\frac{n_i+1}{1+\alpha(n_i+1)} + \frac{n_j+1}{1+\alpha(n_j+1)} - \frac{n_i}{1+\alpha n_i} - \frac{n_j}{1+\alpha n_j} \right] \\ &\simeq \frac{\alpha\sigma}{(1+\alpha(n_i+1))(1+\alpha n_i)} + \frac{\alpha\sigma}{(1+\alpha(n_j+1))(1+\alpha n_j)}\end{aligned} \tag{81}$$

On the other hand,

$$\begin{aligned}\Delta B_i^2 + \Delta B_j^2 \simeq\ & \alpha^2\sigma^2 \frac{-\alpha}{(1+\alpha(n_i+1))(1+\alpha n_i)} \sum\nolimits_{h \in N(i)} \frac{n_h}{1+\alpha n_h} \\ & + \alpha\sigma^2 \frac{1}{1+\alpha(n_i+1)} \frac{\alpha n_j}{1+\alpha n_j} \\ & + \alpha^2\sigma^2 \frac{-\alpha}{(1+\alpha(n_j+1))(1+\alpha n_j)} \sum\nolimits_{h \in N(j)} \frac{n_h}{1+\alpha n_h} \\ & + \alpha\sigma^2 \frac{1}{1+\alpha(n_j+1)} \frac{\alpha n_i}{1+\alpha n_i}\end{aligned} \tag{82}$$

Finally,

$$\begin{aligned}\sum_{h \in N(i) \cup N(j)} \Delta B_h^2 =\ & \frac{\alpha^2\sigma^2}{(1+\alpha(n_i+1))(1+\alpha n_i)} \sum_{h \in N(i)} \frac{1}{1+\alpha n_h} \\ & + \frac{\alpha^2\sigma^2}{(1+\alpha(n_j+1))(1+\alpha n_j)} \sum_{h \in N(j)} \frac{1}{1+\alpha n_h}\end{aligned} \tag{83}$$

Therefore,

$$\begin{aligned}\Delta \sum_{k=1}^{N} B_k =\ & \frac{\alpha\sigma}{(1+\alpha(n_i+1))(1+\alpha n_i)} + \frac{\alpha\sigma}{(1+\alpha(n_j+1))(1+\alpha n_j)} \\ & + \alpha\sigma^2 \frac{1}{1+\alpha(n_j+1)} \frac{\alpha n_i}{1+\alpha n_i} \\ & + \alpha\sigma^2 \frac{1}{1+\alpha(n_i+1)} \frac{\alpha n_j}{1+\alpha n_j} \\ & + \alpha^2\sigma^2 \frac{1}{(1+\alpha(n_i+1))(1+\alpha n_i)} (1-\alpha) \sum\nolimits_{h \in N(i)} \frac{n_h}{1+\alpha n_h} \\ & + \alpha^2\sigma^2 \frac{1}{(1+\alpha(n_j+1))(1+\alpha n_j)} (1-\alpha) \sum\nolimits_{h \in N(j)} \frac{n_h}{1+\alpha n_h}\end{aligned} \tag{84}$$

Finally, recall that the equilibrium price is given by

$$p = \frac{\omega}{\nu}\left[\frac{1}{1-\sigma}\frac{1}{\overline{\overline{B}}} - 1\right]^{-1} \tag{85}$$

with $\overline{B} = \frac{1}{N}\sum_{k=1}^{N} B_k$. Therefore, as the first two terms increase strictly, and we can ignore the higher order terms, by suitably lowering α, the sum $\overline{B}$ increases when a new link is added. This implies that the equilibrium price also increases.

■

Proof of Proposition 3: Fix a network $g \neq g^c$; the critical link g_{ij}, solves the following problem:

$$\max_{g_{ij}} \bar{B}(g+g_{ij}) - \bar{B}(g). \tag{86}$$

We note from proof of Proposition 2, that for small enough α this is equivalent to a link which maximizes the first order effects of a change in network, i.e., maximizes $\Delta B_i^1 + \Delta B_j^1$. From equation (81) the first order effects of a link between i and j are given by:

$$\begin{aligned}\Delta B_i^1 + \Delta B_j^1 &\simeq \alpha\sigma\left[\frac{n_i+1}{1+\alpha(n_i+1)} + \frac{n_j+1}{1+\alpha(n_j+1)} - \frac{n_i}{1+\alpha n_i} - \frac{n_j}{1+\alpha n_j}\right] \\ &\simeq \frac{\alpha\sigma}{(1+\alpha(n_i+1))\,(1+\alpha n_i)} + \frac{\alpha\sigma}{(1+\alpha(n_j+1))\,(1+\alpha n_j)}\end{aligned} \tag{87}$$

So the critical link maximizes the expression in (87); the proof now follows.

■

Proof of Proposition 4: First, consider the change in the consumption of the socially sensitive good by an agent h with $h \neq i, j$ when a link is added between i and j.Let $\widetilde{y}_h$ denote the corrected value of y_h. A similar convention is used for the other variables. We have

$$\widetilde{y}_h = \frac{\widetilde{B}_h}{\sum_{k=1}^{N}\widetilde{B}_k} N\nu \tag{88}$$

It will turn out that first order terms are sufficient to characterise the bahavior as $\alpha \mapsto 0$. From last section we know that this of order:

$$\Delta\Sigma \equiv \sum_{k=1}^{N}\widetilde{B}_k - \sum_{k=1}^{N} B_k = \frac{\alpha\sigma}{(1+\alpha(n_i+1))\,(1+\alpha n_i)} + \frac{\alpha\sigma}{(1+\alpha(n_j+1))\,(1+\alpha n_j)} \tag{89}$$

Furthermore, $\Delta B_h^1 = 0$. Then

$$
\begin{aligned}
\widetilde{y}_h - y_h &= \frac{B_h}{\Delta\Sigma + \sum_{k=1}^N B_k} N\nu - \frac{B_h}{\sum_{k=1}^N B_k} N\nu \\
&= N\nu \left(\frac{(B_h)\left(\sum_{k=1}^N B_k\right) - (B_h)\left(\Delta\Sigma + \sum_{k=1}^N B_k\right)}{\left(\Delta\Sigma + \sum_{k=1}^N B_k\right)\left(\sum_{k=1}^N B_k\right)} \right) \\
&= N\nu \left(\frac{-B_h \Delta\Sigma}{\left(\Delta\Sigma + \sum_{k=1}^N B_k\right)\left(\sum_{k=1}^N B_k\right)} \right) \\
&\simeq -N\nu\Delta\Sigma \frac{B_h}{\left(\sum_{k=1}^N B_k\right)^2} \qquad (90)
\end{aligned}
$$

As $\alpha \mapsto 0$ we get

$$
\widetilde{y}_h - y_h \simeq -2N\nu\alpha\sigma \frac{B_h}{\left(\sum_{k=1}^N B_k\right)^2} \leq 0 \qquad (91)
$$

Remark: We only need $\alpha n_i << 1$ so that $(1 + \alpha(n_i + 1))(1 + \alpha n_i) \simeq 1$ for all i.

We now analyze the effect on the agents who have formed a link. Again consider only the first order terms. We have

$$
\widetilde{y}_i \simeq \frac{B_i + \frac{\alpha\sigma}{(1+\alpha(n_i+1))(1+\alpha n_i)}}{\Delta\Sigma + \sum_{k=1}^N B_k} N\nu \qquad (92)
$$

and

$$
\widetilde{y}_j \simeq \frac{B_j + \frac{\alpha\sigma}{(1+\alpha(n_j+1))(1+\alpha n_j)}}{\Delta\Sigma + \sum_{k=1}^N B_k} N\nu \qquad (93)
$$

Therefore,

$$
\widetilde{y}_i - y_i \simeq \frac{B_i + \frac{\alpha\sigma}{(1+\alpha(n_i+1))(1+\alpha n_i)}}{\Delta\Sigma + \sum_{k=1}^N B_k} N\nu - \frac{B_i}{\sum_{k=1}^N B_k} N\nu \qquad (94)
$$

Similarly,

$$
\widetilde{y}_j - y_j \simeq \frac{B_i + \frac{\alpha\sigma}{(1+\alpha(n_j+1))(1+\alpha n_j)}}{\Delta\Sigma + \sum_{k=1}^N B_k} N\nu - \frac{B_j}{\sum_{k=1}^N B_k} N\nu \qquad (95)
$$

So that the aggregate change in consumption of socially sensitive good by i and j is:

$$y_i - y_i + y_j - y_j] = \frac{B_i + B_j + \Delta\Sigma}{\Delta\Sigma + \sum_{k=1}^{n} B_i} - \frac{B_i + B_j}{\sum_{k=1}^{n} B_k} > 0. \tag{96}$$

We now examine the effects on demand of good 1, when a single connection is added to the network between i and j. Assume that $(1 + \alpha(n_i + 1))(1 + \alpha n_i) \simeq 1$ or equivalently that $\alpha n_i << 1$, for all i then. For agent i, we have

$$\begin{aligned} \frac{1}{\omega}\widetilde{x}_i &= \frac{N - (1-\sigma)N\widetilde{B}_i}{N - (1-\sigma)\sum_{k=1}^{N}\widetilde{B}_k} \\ &\simeq \frac{N - (1-\sigma)N(\alpha\sigma + B_i)}{N - (1-\sigma)[2\alpha\sigma + \sum_{k=1}^{N} B_k]} \end{aligned} \tag{97}$$

Therefore

$$\frac{1}{\omega N}\Delta x_i = \frac{1}{\omega N}(\widetilde{x}_i - x_i) \tag{98}$$

$$\begin{aligned} &= \frac{1 - (1-\sigma)(\alpha\sigma + B_i)}{N - (1-\sigma)[2\alpha\sigma + \sum_{k=1}^{N} B_k]} \\ &\quad - \frac{1 - (1-\sigma)B_i}{N - (1-\sigma)\sum_{k=1}^{N} B_k} \end{aligned} \tag{99}$$

After reducing to a common denominator, the numerator becomes

$$\begin{aligned} Num &= [1 - (1-\sigma)(\alpha\sigma + B_i)][N - (1-\sigma)\sum_{k=1}^{N} B_k] \\ &\quad -[1 - (1-\sigma)B_i][N - (1-\sigma)[2\alpha\sigma + \sum_{k=1}^{N} B_k]] \end{aligned} \tag{100}$$

Let

$$A_1 = 1 - (1-\sigma)B_i \ \text{ and } A_2 = N - (1-\sigma)\sum_{k=1}^{N} B_k \tag{101}$$

Then

$$\begin{aligned} Num &= [A_1 - (1-\sigma)\alpha\sigma)][A_2] - [A_1][A_2 - (1-\sigma)2\alpha\sigma] \\ &= [-(1-\sigma)(\alpha\sigma)]A_2 + A_1(1-\sigma)2\alpha\sigma \\ &= [(1-\sigma)\alpha\sigma][2A_1 - A_2] \end{aligned} \tag{102}$$

Then

$$\begin{aligned} Num &= [(1-\sigma)\alpha\sigma] \\ &\quad [2 - 2(1-\sigma)B_i - N + (1-\sigma)\sum_{k=1}^{N} B_k] \\ &= [(1-\sigma)\alpha\sigma]\left(2 - N + (1-\sigma)\left[\sum_{k=1}^{N} B_k - 2B_i\right]\right) \end{aligned} \tag{103}$$

Finally we get

$$\Delta x_i = \omega N[(1-\sigma)\alpha\sigma] \frac{2 - N + (1-\sigma)[\sum_{k=1}^{N} B_k - 2B_i]}{\left(N - (1-\sigma)[2\alpha\sigma + \sum_{k=1}^{N} B_k\right)\left(N - (1-\sigma)\sum_{k=1}^{N} B_k\right)} \quad (104)$$

Note that the condition for a positive price is $(1-\sigma)\sum_{k=1}^{N} B_k < N$ and that $B_i > 1$ by construction. Therefore, $\Delta x_i < 0$.

For a node h with $h \neq i, j$, the increase in consumption of first good is computed as follows.

$$\begin{aligned} \frac{1}{\omega}\Delta x_h &= \frac{1}{\omega}(\widetilde{x}_h - x_h) \\ &= \frac{N - (1-\sigma)NB_h}{N - (1-\sigma)[2\alpha\sigma + \sum_{k=1}^{N} B_k]} \\ &\quad - \frac{N - (1-\sigma)NB_h}{N - (1-\sigma)[\sum_{k=1}^{N} B_k]} \end{aligned} \quad (105)$$

First observe that $\Delta x_h/\omega > 0$, as $N - (1-\sigma)[\sum_{k=1}^{N} B_k] > 0$. After reducing to the same denominator, the numerator becomes:

$$\begin{aligned} Num &= [N - (1-\sigma)NB_h] \\ &\quad \left[\left(N - (1-\sigma)[\sum_{k=1}^{N} B_k]\right) - \left(N - (1-\sigma)[2\alpha\sigma + \sum_{k=1}^{N} B_k]\right)\right] \\ &= [N - (1-\sigma)NB_h]\,[(1-\sigma)2\alpha\sigma] \\ &= N(1-\sigma)2\alpha\sigma - (1-\sigma)^2 2\alpha\sigma NB_h \\ &= N(1-\sigma)2\alpha\sigma\,[1 - (1-\sigma)B_h] \end{aligned} \quad (106)$$

Therefore the increase in x_h decreases with the (relative) centrality of h; in other words, for fixed $\sum B_i$, an increase in B_h reduces the increase in demand for good 1. ■

Proposition 9 *Suppose that all agents have the same degree in a social network. Then equilibrium prices are independent of the precise structure of the network.*

Proof: Recall that demand is given by:

$$f_i^1(p, \{y_j\}_{j\in N(i)}) = \sigma\left(\omega_i + p\nu_i - \frac{\alpha}{1+\alpha n_i} p \sum_{j\in N(i)} y_j\right)$$

Sum over all agents

$$
\begin{aligned}
& \sum_i f_i^1(p, \{y_j\}_{j\in N(i)}) \\
= \ & R_\nu = \\
= \ & \sigma \sum_i \left(\omega_i + p\nu_i - \frac{\alpha}{1+\alpha n_i} p \sum_{j\in N(i)} y_j \right) \\
= \ & \sigma \left[R_\omega + pR_\nu \right] - \frac{\sigma\alpha}{1+\alpha 2} p \sum_i \sum_{j\in N(i)} y_j \\
= \ & \sigma \left[R_\omega + pR_\nu \right] - \frac{\sigma\alpha}{1+\alpha k} pk \sum_i y_i \\
= \ & \sigma \left[R_\omega + pR_\nu \right] - \frac{\sigma\alpha}{1+\alpha k} pk.R_\nu
\end{aligned}
$$

The last two steps hold because $n_i = k \in \{0, 1, 2, ...n - 1\}$. Finally, the value of p can be obtained as a function of k; it is independent of the details of the network structure. ■

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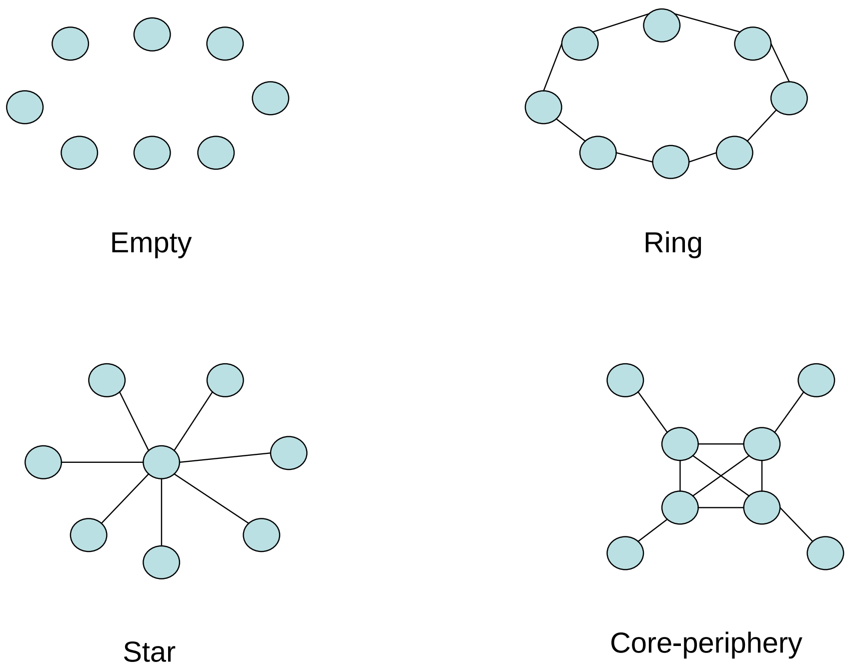

Figure 1: Classical social networks

	Empty	Star	Ring	Core-periphery
x1	10	7.1233	10	8.75
x2	10	10.411	10	8.75
x3	10	10.411	10	8.75
x4	10	10.411	10	8.75
x5	10	10.411	10	11.25
x6	10	10.411	10	11.25
x7	10	10.411	10	11.25
x8	10	10.411	10	11.25
y1	10	11.6279	10	10.6452
y2	10	9.7674	10	10.6452
y3	10	9.7674	10	10.6452
y4	10	9.7674	10	10.6452
y5	10	9.7674	10	9.3548
y6	10	9.7674	10	9.3548
y7	10	9.7674	10	9.3548
y8	10	9.7674	10	9.3548
u1	10	11.3672	10	9.9393
u2	10	9.5919	10	9.9393
u3	10	9.5919	10	9.9393
u4	10	9.5919	10	9.9393
u5	10	9.5919	10	9.8987
u6	10	9.5919	10	9.8987
u7	10	9.5919	10	9.8987
u8	10	9.5919	10	9.8987
Price	1	1.7671	2	1.9375

endow.=10
alpha=0.5
sigma=0.5

Figure 2: Social networks shape general equilibrium

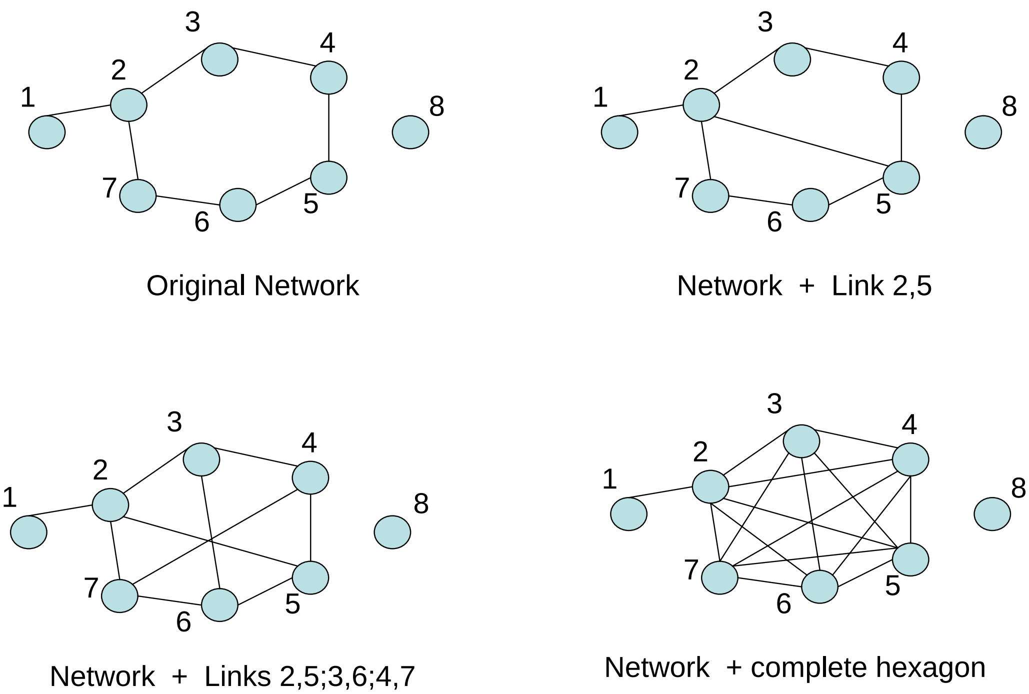

Figure 3: Networks with Isolated Agent

	Ring 2 to 7	Ring+Link 2-5	Ring+2-5,3-6,4-7	Complete hexa
x1	10.7933	11.0183	11.3892	12.4379
x2	8.5529	8.0418	8.2078	8.6765
x3	9.2643	9.4517	8.673	8.2997
x4	9.3545	9.5039	9.6842	8.3345
x5	9.3645	8.5117	8.673	9.1296
x6	9.3545	9.5039	8.7104	8.3345
x7	9.2643	9.4517	9.6307	8.2997
x8	14.0518	14.517	15.0318	16.4877
y1	9.5618	9.465	9.3076	8.9389
y2	10.7994	11.0288	10.8933	10.5761
y3	10.4064	10.2881	10.6614	10.7401
y4	10.3566	10.2606	10.1574	10.7249
y5	10.351	10.7819	10.6614	10.3788
y6	10.3566	10.2606	10.6428	10.7249
y7	10.4064	10.2881	10.1841	10.7401
y8	7.7619	7.6269	7.4921	7.1762
u1	9.8247	9.7813	9.9198	10.0499
u2	10.0508	10.096	9.9846	9.9145
u3	9.7375	9.6886	9.6152	9.484
u4	9.8323	9.7421	9.6569	9.5238
u5	9.8428	9.7549	9.6152	9.5234
u6	9.8323	9.7421	9.6569	9.5238
u7	9.7375	9.6886	9.6152	9.484
u8	10.4436	10.5223	10.7081	10.8775
Price	1.8104	1.9034	2.1133	2.2975

endow.=10.
alpha=0.5
sigma=0.5

Figure 4: No man is an island

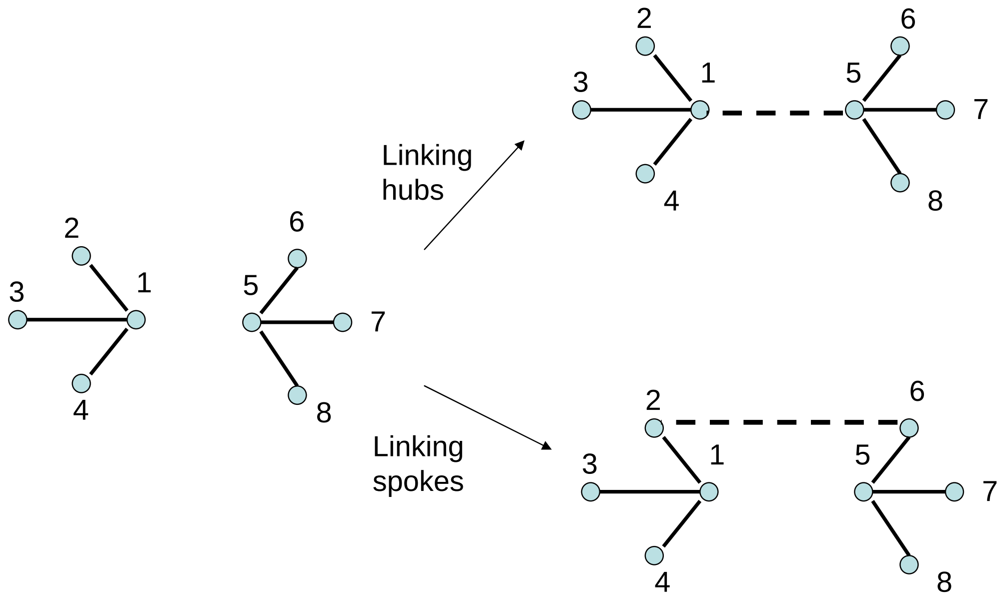

Figure 5: Critical links

	Two Stars	Linked centers	Linked laterals
x1	8.5714	8	8.7943
x2	10.4762	10.6667	9.3617
x3	10.4762	10.6667	10.922
x4	10.4762	10.6667	10.922
x5	8.5714	8	8.7943
x6	10.4762	10.6667	9.3617
x7	10.4762	10.6667	10.922
x8	10.4762	10.6667	10.922
y1	10.8333	11.1111	10.6564
y2	9.7222	9.6296	10.3475
y3	9.7222	9.6296	9.4981
y4	9.7222	9.6296	9.4981
y5	10.8333	11.1111	10.6564
y6	9.7222	9.6296	10.3475
y7	9.7222	9.6296	9.4981
y8	9.7222	9.6296	9.4981
u1	10.351	10.328	10.2596
u2	9.7996	9.7373	9.7685
u3	9.7996	9.7373	9.8698
u4	9.7996	9.7373	9.8698
u5	10.351	10.328	10.2596
u6	9.7996	9.7373	9.7685
u7	9.7996	9.7373	9.8698
u8	9.7996	9.7373	9.8698
Price	1.7143	1.8	1.8369

endow.=10
alpha=0.5
sigma=0.5

Figure 6: Critical link: moderate social influences

	Two Stars	Linked centers	Linked laterals
x1	8.2803	7.6246	8.5398
x2	10.5732	10.7918	9.0567
x3	10.5732	10.7918	11.2017
x4	10.5732	10.7918	11.2017
x5	8.2803	7.6246	8.5398
x6	10.5732	10.7918	9.0567
x7	10.5732	10.7918	11.2017
x8	10.5732	10.7918	11.2017
y1	10.7567	10.9837	10.5869
y2	9.7478	9.6721	10.3791
y3	9.7478	9.6721	9.517
y4	9.7478	9.6721	9.517
y5	10.7567	10.9837	10.5869
y6	9.7478	9.6721	10.3791
y7	9.7478	9.6721	9.517
y8	9.7478	9.6721	9.517
u1	10.5653	10.5237	10.414
u2	9.6677	9.5729	9.6077
u3	9.6677	9.5729	9.7888
u4	9.6677	9.5729	9.7888
u5	10.5653	10.5237	10.414
u6	9.6677	9.5729	9.6077
u7	9.6677	9.5729	9.7888
u8	9.6677	9.5729	9.7888
Price	2.2726	2.4147	2.4881

Endow=10
alpha=0.9
sigma=0.5

Figure 7: Critical link: high social influence

	Endowments	Two Stars	Linked centers	Linked laterals
x1	20	23.4375	22.7273	24.0061
x2	10	8.8542	9.0909	7.7982
x3	10	8.8542	9.0909	9.0979
x4	10	8.8542	9.0909	9.0979
x5	20	23.4375	22.7273	24.0061
x6	10	8.8542	9.0909	7.7982
x7	10	8.8542	9.0909	9.0979
x8	10	8.8542	9.0909	9.0979
y1	20	18.254	18.75	18.0535
y2	10	10.582	10.4167	11.0698
y3	10	10.582	10.4167	10.4383
y4	10	10.582	10.4167	10.4383
y5	20	18.254	18.75	18.0535
y6	10	10.582	10.4167	11.0698
y7	10	10.582	10.4167	10.4383
y8	10	10.582	10.4167	10.4383
u1		26.4111	26.6501	26.4581
u2		7.7286	7.5378	7.6873
u3		7.7286	7.5378	7.767
u4		7.7286	7.5378	7.767
u5		26.4111	26.6501	26.4581
u6		7.7286	7.5378	7.6873
u7		7.7286	7.5378	7.767
u8		7.7286	7.5378	7.767
Price		1.9688	2.1818	2.0581

alpha=0.5
sigma=0.5

Figure 8: Adding links: rich central agents

	Endowments	Two Stars	Linked centers	Linked laterals
x1	10	6.9444	6.4103	7.1429
x2	20	23.1481	23.5043	21.4286
x3	10	9.9537	10.0427	10.7143
x4	10	9.9537	10.0427	10.7143
x5	10	6.9444	6.4103	7.1429
x6	20	23.1481	23.5043	21.4286
x7	10	9.9537	10.0427	10.7143
x8	10	9.9537	10.0427	10.7143
y1	10	11.8644	12.1212	11.5385
y2	20	18.0791	17.9293	19.2308
y3	10	10.0282	9.9747	9.6154
y4	10	10.0282	9.9747	9.6154
y5	10	11.8644	12.1212	11.5385
y6	10	18.0791	17.9293	19.2308
y7	10	10.0282	9.9747	9.6154
y8	10	10.0282	9.9747	9.6154
u1		8.5769	8.5349	8.2874
u2		22.1456	22.1285	22.2375
u3		9.5226	9.4549	9.6291
u4		9.5226	9.4549	9.6291
u5		8.5769	8.5349	8.2874
u6		22.1456	22.1285	22.2375
u7		9.5226	9.4549	9.6291
u8		9.5226	9.4549	9.6291
Price		1.6389	1.6923	1.8571

alpha=0.5
sigma=0.5

Figure 9: Adding links: poor central agents

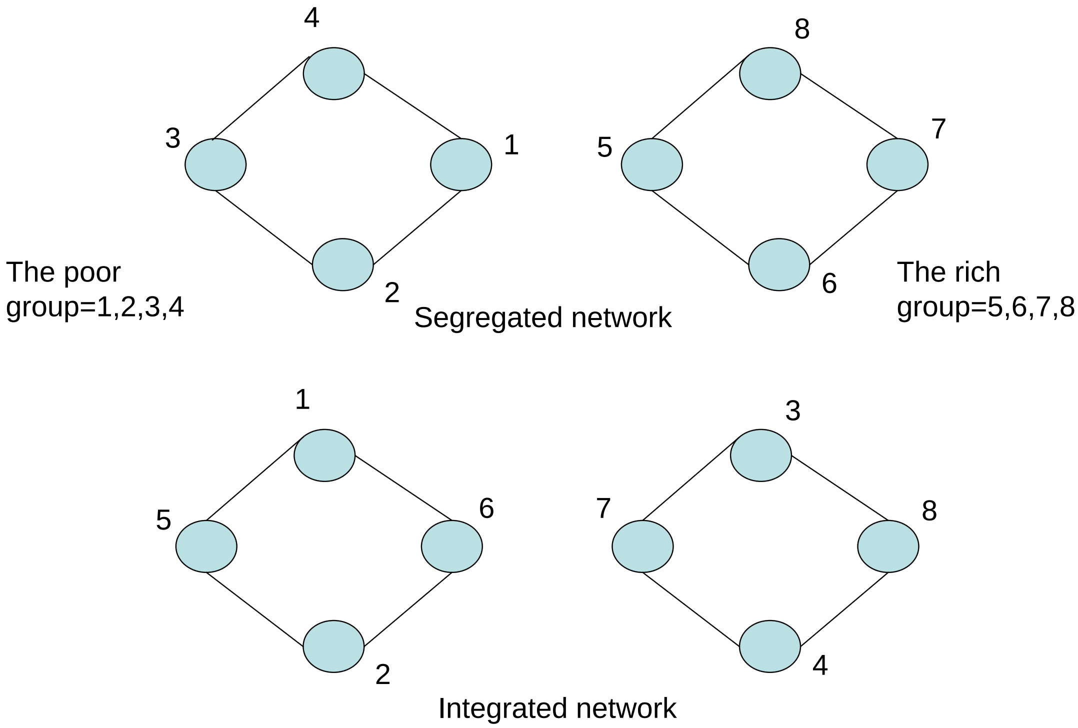

Figure 10: Segregated and integrated societies

	Endowments	Segregated	Integrated
x1	5	5	3
x2	5	5	3
x3	5	5	3
x4	5	5	3
x5	10	10	12
x6	10	10	12
x7	10	10	12
x8	10	10	12
y1	1	1	1.2
y2	1	1	1.2
y3	1	1	1.2
y4	1	1	1.2
y5	2	2	1.8
y6	2	2	1.8
y7	2	2	1.8
y8	2	2	1.8
u1	2.2361	2.2361	1.3416
u2	2.2361	2.2361	1.3416
u3	2.2361	2.2361	1.3416
u4	2.2361	2.2361	1.3416
u5	4.4721	4.4721	5.3666
u6	4.4721	4.4721	5.3666
u7	4.4721	4.4721	5.3666
u8	4.4721	4.4721	5.3666
Price		10	10

alpha=0.5
sigma=0.5

Figure 11: Keeping up with the neighbors

	Endowments	Rich hub	Rich spike
x1	5	3.5	3.2551
x2	1	1.2143	1.2551
x3	1	1.2143	1.2551
x4	1	1.2143	1.2551
x5	1	1.2143	1.2551
x6	1	1.2143	1.2551
x7	1	1.2143	1.2551
x8	1	1.2143	1.2143
y1	1	1.5185	1.8085
y2	1	0.9259	0.8818
y3	1	0.9259	0.8818
y4	1	0.9259	0.8818
y5	1	0.9259	0.8818
y6	1	0.9259	0.8818
y7	1	0.9259	0.8818
y8	1	0.9259	0.9007
u1		2.5203	2.7137
u2		0.8744	1.0464
u3		0.8744	1.0464
u4		0.8744	1.0464
u5		0.8744	1.0464
u6		0.8744	1.0464
u7		0.8744	1.0464
u8		0.8744	1.0123
Price		2.8929	2.1582

alpha=0.5
sigma=0.5

Figure 12: Neighbor averages in an unequal society

	Endowments	Two Stars	Linked centers	Linked laterals
x1	20	24.2188	24.0741	23.7327
x2	10	8.5938	8.642	9.447
x3	10	8.5938	8.642	8.4101
x4	10	8.5938	8.642	8.4101
x5	20	24.2188	24.0741	23.7327
x6	10	8.5938	8.642	9.447
x7	10	8.5938	8.642	8.4101
x8	10	8.5938	8.642	8.4101
y1	20	17.5676	17.7083	17.7686
y2	10	10.8108	10.7639	10.3306
y3	10	10.8108	10.7639	10.9504
y4	10	10.8108	10.7639	10.9504
y5	20	17.5676	17.7083	17.7686
y6	10	10.8108	10.7639	10.3306
y7	10	10.8108	10.7639	10.9504
y8	10	10.8108	10.7639	10.9504
u1		22.523	22.1134	22.4734
u2		7.992	7.9382	8.9457
u3		7.992	7.9382	7.9639
u4		7.992	7.9382	7.9639
u5		22.523	22.1134	22.4734
u6		7.992	7.9382	8.9457
u7		7.992	7.9382	7.9639
u8		7.992	7.9382	7.9639
Price		1.7344	1.7778	1.6728

alpha=0.5
sigma=0.5

Figure 13: Averages: Changing network with rich central agents

	Endowments	Two Stars	Linked centers	Linked laterals
x1	10	9.0278	9.1398	9.1767
x2	20	21.7593	21.6846	21.1835
x3	10	9.6065	9.5878	9.8199
x4	10	9.6065	9.5878	9.8199
x5	10	9.0278	9.1398	9.1767
x6	20	21.7593	21.6846	21.1835
x7	10	9.6065	9.5878	9.8199
x8	10	9.6065	9.5878	9.8199
y1	10	10.6796	10.6061	10.5536
y2	20	18.7702	18.8131	19.2042
y3	10	10.2751	10.2904	10.1211
y4	10	10.2751	10.2904	10.1211
y5	10	10.6796	10.6061	10.5536
y6	20	18.7702	18.8131	19.2042
y7	10	10.2751	10.2904	10.1211
y8	10	10.2751	10.2904	10.1211
u1		9.2443	9.3959	9.2163
u2		22.2811	22.2921	21.275
u3		9.8369	9.8564	9.8623
u4		9.8369	9.8564	9.8623
u5		9.2443	9.3959	9.2163
u6		22.2811	22.2921	21.275
u7		9.8369	9.8564	9.8623
u8		9.8369	9.8564	9.8623
Price		1.4306	1.4194	1.4871

alpha=0.5
sigma=0.5

Figure 14: Averages: Changing network with poor central agents

	Endowments	Segregated	Integrated
x1	5	5	3.9286
x2	5	5	3.9286
x3	5	5	3.9286
x4	5	5	3.9286
x5	10	10	11.0714
x6	10	10	11.0714
x7	10	10	11.0714
x8	10	10	11.0714
y1	1	1	1.1429
y2	1	1	1.1429
y3	1	1	1.1429
y4	1	1	1.1429
y5	2	2	1.8571
y6	2	2	1.8571
y7	2	2	1.8571
y8	2	2	1.8571
u1		2.2361	1.7569
u2		2.2361	1.7569
u3		2.2361	1.7569
u4		2.2361	1.7569
u5		4.4721	4.9513
u6		4.4721	4.9513
u7		4.4721	4.9513
u8		4.4721	4.9513
Price		7.5	7.5

alpha=0.5
sigma=0.5

Figure 15: Averages: Segregation *vs* integration