Seller Automata in a Model of Exchange

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Abstract: This model simulates a simple exchange economy made up of geographically dispersed, rationally bounded agents with spatially correlated initial endowments who incur transactions costs in the process of trading. Agents are able to advertise globally at no cost in order to inform other agents of potential trading opportunities, but they must pay a transaction cost proportional to the distance traveled to visit an agent in order to engage in trade. Although trade is shown to improve the efficiency of the economy in most cases, a negative search externality occurs at low transaction resulting in over-trading and a loss of efficiency. The effect of trade on inequality depends on the measure of wealth. The presence of highly spatially correlated initial endowments is shown to diminish slightly the benefits of trade relative to the randomly allocated initial endowments case.

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1. Introduction

This paper simulates a simple exchange economy made up of geographically dispersed agents with spatially correlated initial endowments who incur transactions costs in the process of trading. Agents are able to advertise globally at no cost in order to inform other agents of potential trading opportunities, but they must pay a transaction cost proportional to the distance traveled to visit an agent in order to engage in trade.

This paper extends work done by Peter Albin and Duncan K. Foley (1992) and thus retains the key features of their model: exchange of goods is decentralized and between geographically dispersed agents. As described in Albin-Foley, exchange is decentralized in that (1) agents initiate trade by themselves by signaling, or equivalently, advertising their willingness to trade, (2) agents engage in bilateral bargaining to determine an exchange price, and (3) agents use the information gathered in the process of trading combined with other agents' signals to calculate trading strategies in future rounds of trading. Trade is between geographically dispersed agents in that agents are positioned along a circle and must travel to other agents on the circle in order to attempt to trade with them.

The differences between the Albin-Foley model and the one presented in this paper arise from a difference in the nature and cost of the signals agents are assumed to be able to transmit to other agents, and from differences in the trading protocols of the models. Agents in the Albin-Foley model can send costly Buy or Sell signals and are only allowed to trade with agents advertising on the other side of the market. Advertising and trade is restricted to a small fixed neighborhood of traders around an agent, and the cost of advertising is proportional to the size of the neighborhood. Once agents advertise, they can trade at no cost with any other agent in the neighborhood that advertised on the other side of the market. In the process of trade, agents learn each others' marginal rates of substitution and use that information in choosing whether or not to issue buy or sell signals in the next round of trading.

In the model presented below, agents directly advertise their marginal rates of substitution instead of specifying buy or sell signals. Thus, an agent can be on the buy-side in one trade and on the sell-side in another. Furthermore, the signals are transmitted globally to all other agents in an approximation of newspaper-type advertisement at no cost. Agents are allowed to travel as far around the circle as desired to engage in trade making the neighborhood size of an agent endogenous. There are two separate trading protocols incorporated in the paper's model that deal with the incidence of transaction costs labeled direct trading and indirect trading. Direct trading allows agents to visit and trade with as many other agents as desired, but a transaction cost proportional to the distance traveled from the agent's home position is incurred for each agent visited. In indirect trading, a transaction cost is only incurred for the most distant agent visited, and the agent can visit and trade with any agents along the way to the most distant agent at no cost. The differences in advertising and trading protocols effectively give the agents in this model much greater memory and calculation capacity than in the Albin-Foley model, but some limits on rationality are imposed as will be observed below.

One feature that is added to the model is the introduction of spatially correlated initial endowments. Rather than simply randomly allocating the initial endowments of agents, regions of relatively high concentration of similarly endowed agents are created via a sorting algorithm. Presumably agents in this economy will have to travel farther to find beneficial trades as compared to the randomly allocated case introducing the possibility of regional effects on trade outcomes. Regional effects were observed in the Albin-Foley simulation results, but those effects arose from the fixed neighborhood of agents with whom advertising and trade was allowed.

Trade is shown to improve the efficiency of the economy in most cases, but the accuracy of advertised information depreciates so rapidly in the process of trading that there is a range of transaction costs where efficiency actually falls as a result of trade. Increasing transaction costs diminish this depreciation of information by curtailing trade, and this trade-off results in a range of transaction costs where efficiency is not decreasing in transaction costs. This phenomena is apparently very dependent on the strategies agents use to decide which other agents to visit. In the direct trading case, the non-monotonicity of efficiency in transaction costs disappears when agents employ a strategy that allows them to stop trading after a utility-losing trade attempt is made.[1]

The issue of information depreciation does not arise in the Albin-Foley model where the fixed neighborhood size keeps agents from pursuing over-optimistic trading strategies. Instead, trade is always beneficial to the economy except when agents continue to advertise fruitlessly after all the trading opportunities have been exploited. Increasing advertising costs reduce the gains from trade as do reductions in the fixed neighborhood size available to agents for trade.

In regard to inequality, both trading protocols perform similarly to the Albin-Foley model showing an increase in inequality in the economy as measured by wealth at Walrasian equilibrium prices. Utility inequality falls in the direct trading case and increases in the indirect trading case. Who benefits the most from trade depends heavily on the order of trade in the first trading round since most trading opportunities are exploited quickly. Agents engage in trade in a randomly determined order, and those agents that trade early in the round tend to receive the largest benefits from trade. As agents' marginal rates of substitutions are the most dispersed before trade

[1] The nature of the indirect trading protocol does not allow for such a stopping rule in agents' strategies as will be discussed below.

commences, the first agents that engage in trade are able to trade at the most favorable prices and therefore capture the most favorable trading opportunities.

Although the trading order seems to be the primary determinant of an agent's benefit from trade, the position of an agent along the circle is also important as the presence of highly spatially correlated initial endowments tends to lower the increase in efficiency resulting from trade. This effect is very small in the indirect trading case because the trading protocol introduces a kind of increasing returns to transaction costs that makes traveling further around the circle as a result of a lack of trading opportunities nearby very inexpensive. But in the direct trading case, the more highly spatially correlated the initial endowments of agents are, the greater is the distance agents must travel in order to find trading opportunities, and the greater is the loss in the economy's efficiency gain.

The paper is divided into five sections. Section 2 presents a model of exchange. Section 3 discusses the game-theoretic framework of the model and the rationale for the strategies for the players. Section 4 presents the simulation results. Section 5 concludes with suggestions for additional research.

2. A model of exchange

Following Albin-Foley, the exchange economy is comprised of 100 identical, fully rational players geographically arrayed in a circle that have preferences over two goods, X and Y. Each player chooses an agent as a representative to enact her trading strategy. Agents are assumed to be bounded in their rationality and have the same preferences over the two goods as the players, so the payoffs to the players from choosing one particular agent can be observed from the agent's utility.

Preferences for each agent i (and therefore, each player i)[2] are assumed to be represented by a Cobb-Douglas utility function:

$$U_i(X_i,Y_i) = X_iY_i. \tag{2-1}$$

Each agent i has an initial endowment of X and Y such that the sum of the two goods equals 100 and the total sum of X and Y in the economy equals 10,000:

$$X_i + Y_i = 100 \tag{2-2}$$

$$\sum_{i}^{100} X_i + \sum_{i}^{100} Y_i = 10{,}000 \tag{2-3}$$

The X endowments of the agents in the first half of the circle are assumed to be identically and independently uniformly distributed over [0,100]. Given X_i , Y_i satisfies equation 2-2. In order to ensure that the total sum of goods in the economy is equal to 10,000, the agents in the second half of the circle are "matched" with the first half by switching the amounts of X and Y between each agent in the first half of the circle with a corresponding agent in the second half of the circle.

The initial marginal rate of substitution (MRS) [3] of agent i is

$$MRS_i = Y_i / X_i = (100 - X_i) / X_i \tag{3-3}$$

[2] For the sake of exposition, the distinction between players and agents will be suppressed until the next section discussing the choice of strategies of players.

Figure 2-1: Initial Distribution of Log(MRS)—Endowment = Random Case

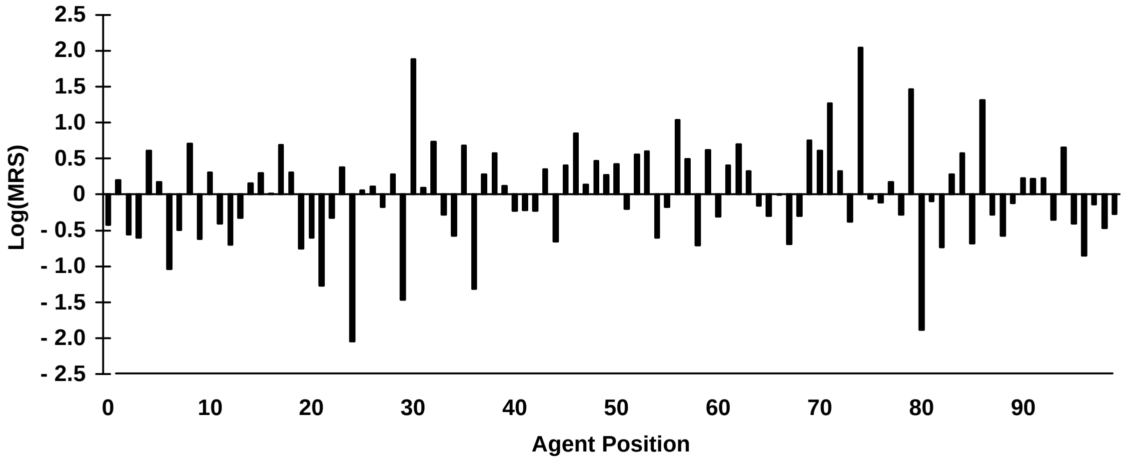

Figure 2-2: Initial Distribution of Log(MRS)—Endowment = Sorted Case

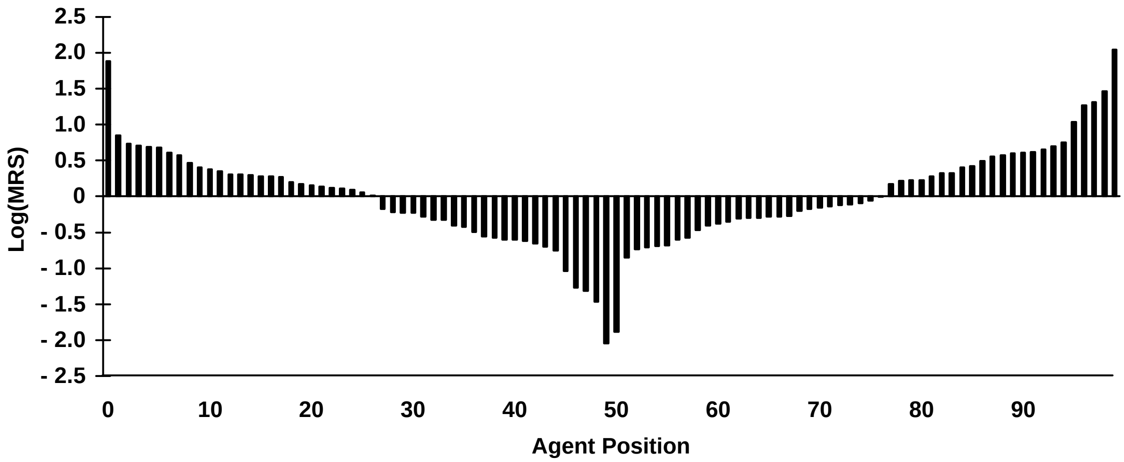

Figure 2-1 shows the initial distribution of the log of the marginal rate of substitution of the agents in the circle for a randomly generated distribution of initial endowments as described above. The initial endowment that is generated in this way is

[3] As shown in Albin-Foley, the cumulative distribution of the marginal rate of substitution for t>0 is given by

$$\begin{aligned} P(MRS < t) &= P(100/X - 1 < t) \\ &= P(X > 100/(t+1)) \\ &= 1 - P(X < 100/(t+1)) \\ &= t/(t+1). \end{aligned}$$

labeled as “Endowment = Random.” The same initial allocation as in Figure 2-1 sorted to create a spatially correlated allocation is shown in Figure 2-2. Obviously this allocation is no longer randomly distributed; it represents the opposite extreme of the Endowment = Random case and is labeled as the “Endowment = Sorted” case. The effect of “matching” is readily apparent in the symmetry of Figure 2-2.

The Walrasian equilibrium for the set of initial conditions described above is easy to calculate. The equilibrium price is one unit of Y per unit of good X, and the final allocation of X and Y is (50, 50) for all agents. Wealth remains unchanged at 100 (measured at Walrasian equilibrium prices), but utility increases to 2,500 for all agents except those whose endowment happened to be equal to the equilibrium level of X and Y. Utility that is initially unequally distributed becomes completely equalized. These results will serve as a benchmark later for comparison with simulation results.

Advertising and Trading Protocols

Before each round of trading, agents advertise their MRS to all other agents in the circle using newspaper-type advertising at no cost.[4] All agents receive such advertising for free, but any agent wanting to trade with an agent that has advertised must pay a transaction cost that is proportional to the distance required to travel around the circle to meet that agent. In particular, two separate trading protocols (labeled direct and indirect trading) embodying this idea are employed to model trade. In both trading protocols, the order that agents engage in trade is randomly determined before each round of trading.

In direct trade, the agent whose turn it is to trade can use the advertised information available on other agents’ marginal rates of substitution to determine which

[4] For all levels of transaction costs, most trading occurs in the first round of trading. Therefore, the assumption of free advertising is almost equivalent to the assumption that every agent advertises before the first round of trade. In any event, the advertising cost is small relative to transaction costs and assumed to be zero for simplicity.

agents to visit. If an agent is visited, a transaction cost proportional to the distance traveled is paid regardless of whether or not trade actually occurs. The transaction cost is paid in terms of the good that the agent has more of at that time. When two agents meet, agents are assumed to reveal truthfully their respective marginal rates of substitution,[5] and the price resulting from the bilateral bargaining between the agents is assumed to be the geometric mean of their marginal rates of substitution. If trade is beneficial to both parties, trade occurs. Note that once trade occurs, the advertised information of the agents not involved in the transaction begins to depreciate as the actual marginal rates of substitution of the trading agents diverge from the advertised rate as a result of trade. As in Albin-Foley, the size of a trade is determined by a parameter called the trade step that equals the amount of good X that is traded. The trade step is assumed to be small and reduces the number of economic choice variables by one. When the agent has finished visiting agents, the next randomly determined agent begins the process until all agents have had a chance to trade.

Indirect trading differs from direct trade in that the only transaction cost that must be paid is for the farthest agent visited. This introduces a kind of increasing returns to transaction costs as many agents can be visited at no cost. The transaction cost must be paid before an agent begins trading so expected gains from trade cannot be used to finance an agent's trading tour around the circle of agents. The source of information and price formation is the same as in direct trading. Before any attempt at trade occurs, each agent can use the available information to determine which agent should be the farthest agent to visit. Again, regardless of whether or not trade actually occurs with the farthest agent visited, a transaction cost proportional to the distance traveled is incurred. As stated above, each agent visited along the way to the farthest agent represents a free trading opportunity, and information on agents' marginal rates of substitution is updated

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[5] The assumption of truthful disclosure will be discussed in more detail below.

regardless of whether or not trade occurs. All agents randomly receive a turn to trade and the round is finished after the last agent finishes visiting agents.

As long as there are some trades executed during a round of trading, another round of trading occurs. This is contrary to the Albin-Foley model where the simulation stops when agents stop advertising.[6] In both models, however, the trading process is transient in that endowments are allocated only once, and trading lasts a limited number of rounds.

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[6] In the Albin-Foley model, there is a possibility of "persistent useless advertising" where a pair of agents continuously advertise in hopes of trading, but always on the wrong side of the market, thus allowing for the possibility of the simulation to continue even when there is no trading between agents.

3. The game-theoretic framework of the model

The process of advertising and trading described above defines a repeated n-person game with restricted information. Even though advertising is free, information is restricted because the advertised MRS information agents use to decide with whom to trade is no longer current once trade begins. As in Albin-Foley, the agents of the economy are "bounded-rationality proxies" of fully rational players. The payoffs to the players are given by the agents' utility functions after all trading ends, so that players choose agents that pursue a trading strategy that is considered optimal given the bounds on rationality placed on the agents. An agent therefore is a mapping from a player's information set to her action set and represents a player's strategy.

There are two possible types of agents in the 2-person version of the game under either trading protocol.[7] The first type is the agent that simply waits for the other agent to visit so that she will not have to expend any resources on transaction costs. The second type is the agent that (1) uses the advertised MRS information to calculate whether visiting the other agent would result in trade, and (2) visits the other agent if trade is calculated to be beneficial. The payoff matrix given only one round of trading, initial endowments of (40,60) and (60,40) for agents A and B respectively, a transaction cost (TC) of 0.1, and a trade step equal to one unit of good X is shown below in Table 3-1.

[7] Assume assumption 2-3 is relaxed so that the sum of total goods in the economy equals 100n where n is the number of players in the game.

Table 3-1: 2-Person Game Payoff Matrix after 1 Round of Trading (a)

		PlayerB	
	(A's Payoff, B's Payoff)	**Agent Waits**	**Agent Visits**
Player A	**Agent Waits**	(2,400.00, 2,400.00)	(2,419.00, 2,414.90)
	Agent Visits	(2,414.90, 2,419.00)	(2,431.85, 2,431.77)[8]

(a) Initial endowments (X,Y) of players A and B respectively are (40,60) and (60,40). The transaction cost is 0.1, and the trade step equals 1 unit of good X.

The Nash equilibrium for one round of trade is clearly for each player to choose an agent that visits the other agent. As long as the game continues until all trading ends, however, the set of agents above is no longer a Nash equilibrium. The best response to an agent that always visits, is simply to choose an agent that only waits for the other agent to visit, thereby avoiding transaction costs completely.[9] Thus, in the multi-round, 2-player version of the game, there are at least two Nash equilibria: one where player A's agent always visits and player B's agent always waits, and vice versa. Notice that because the economy consists of only two agents, the agents' information sets are always current. Thus, agents never make a mistake in their calculations of the net expected benefit of visiting the other agent, and visiting always results in trade.

Extending these strategies to the 3-person version of the game with the direct trading protocol destroys the Nash equilibria described above and reveals the informational problems that arise in higher-dimensional settings. The visiting strategy of the agent in this version of the game would be to (1) calculate the net expected benefit from visiting another agent, (2) visit that agent if the net expected benefit were positive, and (3) repeat steps 1 and 2 for the other agent. The strategy of simply waiting for agents to visit in order to save on transaction costs is no longer a best response

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[8] The payoff assumes A visits B first, and then B visits A. If the order was reversed, the payoff would be (2431.74, 2431.84). This demonstrates that the order of trading matters, but not significantly as long as the marginal rates of substitution of agents are "symmetric" around unity.

because the waiting agent loses trading opportunities to the other two agents (assuming they are engaging in the visiting strategy). In particular, because at the onset of trade the marginal rates of substitution of agents are the most dispersed, the most favorable prices, and thus the best trading opportunities, can be obtained then. Waiting for the agent with the extreme marginal rate of substitution to visit allows the best trades to go to the agents that were visited first or to the agents that visited this extreme agent first.

To see the type of informational problem that arises, label the agents in order that they trade agents A, B and C, and consider what happens when it becomes agent C's turn to trade. If agent B visited agent C, agent C's information on agent B's marginal rate of substitution will be up to date because agents reveal their marginal rates of substitution upon meeting regardless of whether or not trade occurs. But agent C's information on agent A's marginal rate of substitution may no longer be current if agent B visited agent A on her turn. Following the visiting strategy described above, agent C will calculate the net benefit of trade with agent A ignoring the possibility that agent A's marginal rate of substitution may have changed due to trade with agent B. This introduces the possibility of additional strategic behavior to take into account inaccurate information.

Because the trade step is assumed to be small, however, such informational errors will have small effects in the three-person game where all agents engage in the visiting strategy, as many trades will still be beneficial to both parties even though the net expected benefit calculation overstates the actual gains from trade. The potential for serious errors becomes more likely with an increase in the size of the game. Yet possible remedies to this problem impose major informational requirements on the agents. For instance, an agent could conceivably use the advertised information to work

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[9] If agent B waited two rounds for agent A to visit, the resulting payoffs would be (2,427.65, 2435.97) at the end of the second round, improving the payoff to agent B as compared to the strategy of visiting agent A

through the actions of every other agent in order to predict more accurately the marginal rates of substitution of potential trading partners. One immediate problem with this is that the agent would have to infer the order of trade via the order in which other agents visited her and from the information obtained at these meetings. Furthermore, as soon as she began to visit other agents, she would receive new information with which to double-check her projections, and she might have to redo calculations in the middle of traveling to visit other agents. The complexity of the calculations involved in such a strategy might be possible with full rationality, but it seems counter-intuitive to model agents as having the time or computational capacity to perform such calculations.

From this exercise it should be immediately clear that listing the possible agent types available to players to choose from, and then determining the set of Nash equilibria among these agents is not a viable method of analyzing the outcomes of this game with more than a few players. Instead this paper follows Albin-Foley in suggesting candidate trade algorithms for all agents to follow (one each for the direct and indirect trading protocols) and examines the properties of the resulting trade for these algorithms. The remainder of this section discusses key behavioral assumptions of the agents and finally describes the candidate algorithms for the agents.

Truthful Disclosure

Agents are assumed to reveal truthfully their marginal rates of substitution both when they advertise and when they meet another agent to trade. When advertising, agents have an incentive to exaggerate their willingness to trade one good for the other in an effort to induce other agents to visit. This “bait and switch” strategy, however, contradicts the type of lie that agents have an incentive to make once they actually meet other agents. Because agents know the exchange price will fall between the agents’ revealed marginal rates of substitution, agents have an incentive to downplay their

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in the first round.

willingness to trade when they meet other agents. These opposing forces would make it more difficult, but not impossible for an agent to lie effectively. Of course, if both agents on opposite sides of the market lied to the same degree, the price as measured by the arithmetic mean of the marginal rates of substitution would be unaffected. This rationalization of truthful disclosure is less attractive in this model since the exchange price equals the geometric mean. But as Albin-Foley argue, as long as the trade step is small, the assumption is not implausible as the possible gains from lying are limited.

Computational Capacity of Agents

As motivated at the beginning of the section, agents are assumed to be bounded in their rationality on the grounds that they have limited time and computational capacity to calculate their optimal trading strategy. This assumption is the same as in Albin-Foley, except that the bounds are considerably more relaxed in this model. In this model, agents are assumed to have enough memory to store the following information: (1) the agent's own holdings of goods X and Y, (2) the transaction cost parameter, (3) a list of advertised marginal rates of substitution that is updated to reflect meetings with other agents, and (4) the results of calculations used in the estimation process before agents decide to visit other agents . The difference between the two models arises from the third category that contains information on all other traders in this model, but only the traders within an agent's neighborhood in the Albin-Foley model.[10] The agents in the Albin-Foley have memory for a few additional parameters related to the advertising decision, but they do not significantly add to the memory requirements of agents.

Candidate Algorithms

The algorithms for both trading protocols are extensions of the visiting strategy of agents discussed at the beginning of this section. In direct trading, an agent uses the list of advertised marginal rates of substitution updated to reflect information gained from agents that visited before it became her turn trade to calculate the net benefit of trade with an agent, and she visits that agent if the net benefit is positive for both agents. The agent starts this process with the agents that are immediately adjacent to her, and progresses outwards in an alternating pattern of agents above and below her on the circle. As she moves outward in this pattern of calculation and trade, it is reasonable to imagine that the agent will notice the depreciation of information when it manifests itself in a shortfall of utility gain from expected utility gain from trade. The candidate algorithm should allow an agent to react to this information and thus introduces a stopping rule which is for an agent to continue the pattern of calculation and trade until a utility-losing visit occurs.[11] If the stopping rule is not invoked, after all agents are considered for trade, the next randomly determined agent begins the above process.

In indirect trading, an agent uses the list of updated advertised marginal rates of substitution to estimate which of the other agents in either the up- or down-the-circle direction is the best most distant agent to visit. After determining which agent to visit, the agent proceeds to visit that agent, visiting all other agents in between the most distant agent at no cost. Note that because the transaction cost is paid before the agent begins trading, she cannot adjust her trading strategy in the middle of her turn as can the agent in the direct trading protocol.

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10 The largest neighborhood size in Albin-Foley is equal to five agents.

11 The results section briefly examines the effect of not including this stopping rule.

4. Simulation results

The definitions and abbreviations of the parameters of the model and the statistics of interest generated by the simulations are summarized below in Table 4-1 and Table 4-2. The results presented will generally be from illustrative runs of the simulation rather than averages over many simulations because the results were qualitatively robust from one simulation to the next. Simulations with the same value of the “Seed” parameter have identical initial conditions. Histograms of wealth and utility are generated using the kernal estimator defined by

$$\hat{f}(x) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right)$$

where h is the window width, K is the kernal function, n is the number observations in the sample, and X_i is the ith sample observation. The standard normal distribution is used as the choice of kernal function[Silverman, 1986].

Table 4-1: Parameter Definitions

Name	Description	Definition
AC	Advertising Cost	The amount of good X or Y that is paid when an agent decides to advertise before a round of trading.
Endowment	Initial Endowment Distribution	The initial allocation of X and Y can be randomly allocated (***Endowment = Random***) or sorted from highest to lowest marginal rate of substitution (***Endowment = Sorted***). See Figures 2-1 and 2-2 for examples of Random and Sorted Endowments. ***Endowment = Shifted*** is the case where the same initial allocation is used in several simulations, but is assigned to different agents in each simulation. The reassignment keeps the initial coefficient of resource utilization constant for each simulation, but changes the spatial correlation of agents' endowments.
RHO	Degree of Spatial Correlation	A measure of the spatial correlation of initial endowments. RHO is the slope term of the following regression of the first 50 agents' X allocations on their left neighbors' values: $X_i = a + bX_{i-1} + e_i$.
Seed	Random Number Seed	The seed determines the starting point of the random number generator, so a different seed produces different initial conditions.
TC	Transaction Cost	The amount of good X or Y an agent must pay to visit the agent immediately adjacent to her. Depending on the trading protocol, the cost to visit agents farther away increases proportionally to TC.
TS	Trade Step	The amount of X exchanged when agents agree to trade. The amount of Y exchanged depends on the exchange price.

Table 4-2: Statistics Definitions

Name	Description	Definition
#Trades	Number of Trades	Gives the number of trades occurring in a round of trading. One trade occurs when an agent visits another agent and they agree to exchange goods.
#Visits	Number of Visits	Gives the number of visits occurring in a round of trading.
%WLost	% of W Lost	The cumulative percentage of wealth lost via transaction costs.
Ave"X"	Average of "X"	Notation for the average of the statistic "X."
AveD	Conditional Average Maximum Distance Traveled	The average maximum distance traveled of those agents that travel to visit other agents.
CRU	Coefficient of Resource Allocation	A measure of efficiency giving the percentage of the original allocation in a Walrasian equilibrium needed to attain the same level of utility attained by the trading model [Debreu (1951)].
D	Maximum Distance Traveled	The maximum distance traveled by an agent in her attempt to trade. This is analogous to neighborhood size of an agent in Albin-Foley in direct trading. In indirect trading, the analog is D/2.
SD"X"	Standard Deviation of "X"	Notation for the standard deviation of the statistic "X."
Skew"X"	Skewness of "X"	Notation for the skewness of the statistic "X" defined by $\frac{1}{n}\sum_{i=1}^{n}(X_i - \overline{X})^3$.
U	Utility	Utility of an agent.
UGap	Utility Gap	The difference between the total expected utility from trade and the actual utility from trade for an agent.
W	Wealth	Wealth of an agent measured at Walrasian equilibrium prices. Since the Walrasian equilibrium price ratio is unity, wealth equals the sum of X and Y.

Direct Trading and Earlier Results

The results of a characteristic simulation of the Albin-Foley model are shown in Table 4-3. Trading served to increase the efficiency of the economy as measured by the coefficient of resource utilization from .7812 to .9454. Wealth decreased on average and became more unequal as a result of trading, but welfare as measured by the level of utility did the opposite. Roughly two percent of good X was dissipated in advertising expense. The intensity of trading (not shown in Table 5-3) quickly fell off after the first few rounds of trading. Nevertheless, trading continued for quite some time as 40 rounds were needed before agents stopped advertising.

Table 4-3: Albin-Foley Model Simulation Results (a) (b)

Round	**CRU**	**%XLost**	**AveU[12]**	**SDU**	**AveW**	**SDW**
Initial	0.7812	0.00	39.1180	10.6	100.00	0.00
Final	0.9707	2.02	48.5975	6.4	98.06	12.95

(a) Parameters: Neighborhood Size=4, AC=0.025.
(b) Reproduced from Albin-Foley 1992.

As the parameter of neighborhood size was increased in the Albin-Foley model, the final coefficient of resource utilization marginally increased. The main difference attributable to increasing the neighborhood size was an increase in the speed at which the final efficiency level was attained at all levels of advertising cost. Conversely, increasing advertising costs lowered the final coefficient of resource utilization for all neighborhood sizes tested.

The results from the direct trading protocol broadly duplicate the earlier results from Albin-Foley. Typical simulation results are shown in Table 4-4. Trading is far more intense in the first round than in the Albin-Foley model, and often all trading opportunities are exploited immediately in that round, but this is because agents are not restricted to visit only a small radius of agents in their immediate neighborhood. Thus, instead of

[12] Using U(X,Y)=XY instead of U(X,Y)=$(XY)^{1/2}$ as in Albin-Foley, the average utility increases from 1,530.2 to 2,361.7.

visiting the same agents over and over again in consecutive rounds of trading, agents travel far around the circle of agents visiting many other agents in very

Table 4-4: Direct Trading Simulation Results for TC=0.05 (a)

Round	CRU	#Trades	#Visits	AvelogMRS	SDlogMRS	AveW	SDW	SkewW
0	.8247	0	0	.000000	14.2813	100.00	0	0
1	.9227	1067	1164	-.008056	1.3251	96.14	13.31	- 3+987.65
2	.9391	427	495	-.001593	1.1300	95.40	14.10	- 4,557.61
3	.9426	180	221	.000332	1.0847	95.19	14.23	- 4,596.31
4	.9434	70	75	.001594	1.0761	95.14	14.27	- 4,601.74
5	.9436	19	21	.001909	1.0748	95.13	14.29	- 4,594.48
6	.9436	1	1	.001938	1.0748	95.13	14.28	- 4,594.30
7	.9436	0	0	.001938	1.0748	95.13	14.28	- 4,594.30

Round	%WLost	AveU	SDU	AveUGap	SDUGap	AveD	SDD
0	0	1,797.59	659.95	0	0	0	0
1	3.86	2,182.16	600.85	105.23	107.65	9.65	9.72
2	4.60	2,255.46	600.21	10.39	7.65	4.55	2.66
3	4.81	2,271.46	601.31	3.39	3.93	2.59	1.43
4	4.86	2,275.47	601.67	0.29	0.86	1.36	0.98
5	4.87	2,276.13	601.75	0.06	0.45	1.10	1.00
6	4.87	2,276.16	601.75	0	0	1.00	1.00
7	4.87	2,276.16	601.75	0	0	0	0

(a) Assumptions: Seed=1, TS=0.7, TC=0.05, Endowment = Random

few rounds of trading. The effect of the stopping rule is evident in that the number of visits never exceeds the number of trades by more than 100 since each agent stops trading after the first useless visit. As the intensity of trading subsides in later rounds, the problem of information depreciation diminishes as can be seen be the fall in the number of useless visits as well as by the fall in the average difference in the expected and actual level of utility derived from trade. This is not surprising since informational errors are more likely to occur when there is a lot of trading going on as each trade results in a larger deviation of the trading agents' marginal rates of substitution from their advertised levels.

Trading is shown to improve the coefficient of resource utilization with most of the improvement occurring in the first round of trading. 4.87% of wealth is expended in transaction costs.[13] As in Albin-Foley, average wealth falls and becomes more unequally distributed as agents dissipate resources in the trading process. In contrast, average utility increases and becomes less unequally distributed. Finally, the effective neighborhood size as measured by the average of the maximum distance agents travel in an attempt to trade falls as trade progresses from a high of approximately 10 agents in the first round of trade.[14]

The evolution of the coefficient of resource utilization as trading progresses from round to round at various levels of transaction is shown in Figure 4-1. As transaction costs increases, the improvement in the coefficient of resource utilization decreases, and most of the improvement occurs in the first round of trading. Trading often lasts up to 12 rounds.

Figure 4-2 shows the relationship between the coefficient of resource utilization and transaction costs for transaction costs ranging from 0 to 10 for the candidate algorithm with and without the stopping rule which causes agents to stop trading after a utility-losing visit occurs. The negative relationship between transaction costs and the coefficient of resource utilization suggested in Figure 4-2 is confirmed for the strategy with the stopping rule (which is the strategy used in all other results).[15] Note that the informational errors that occur are never large enough to cause a fall in the coefficient of resource utilization, but they are significant enough in the no-stopping-rule strategy so

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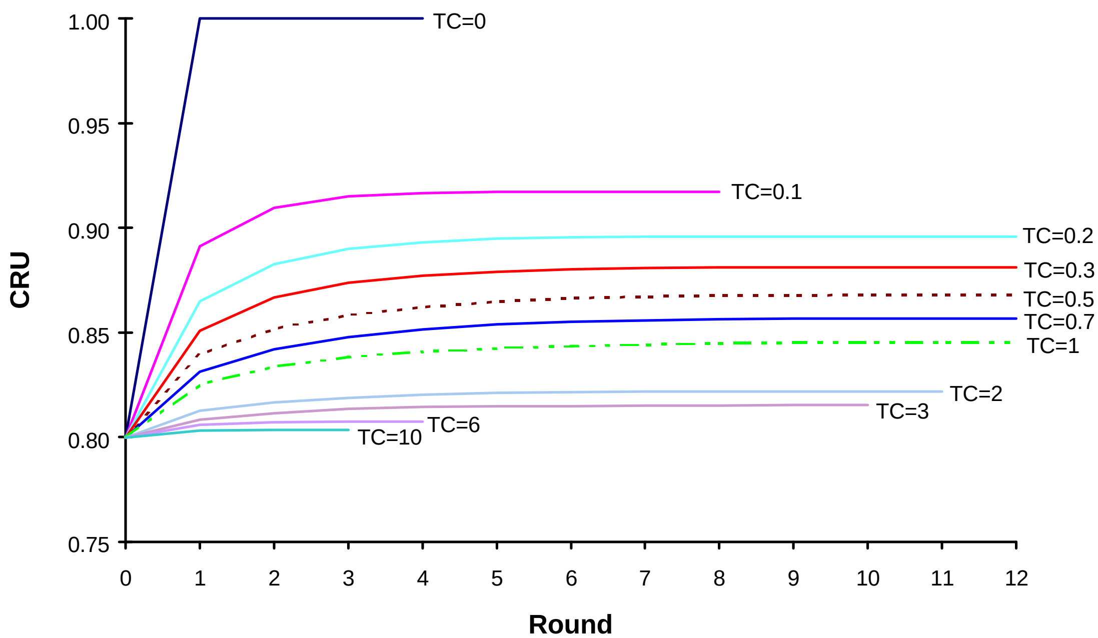
[13] The percentage wealth lost is analogous to the percentage X lost as reported in Albin-Foley. Because of the symmetry of the model's setup, the two values should be roughly equal.

[14] The term "effective" is used because the actual neighborhood size can be larger than the average maximum distance traveled precisely because the statistic is an average.

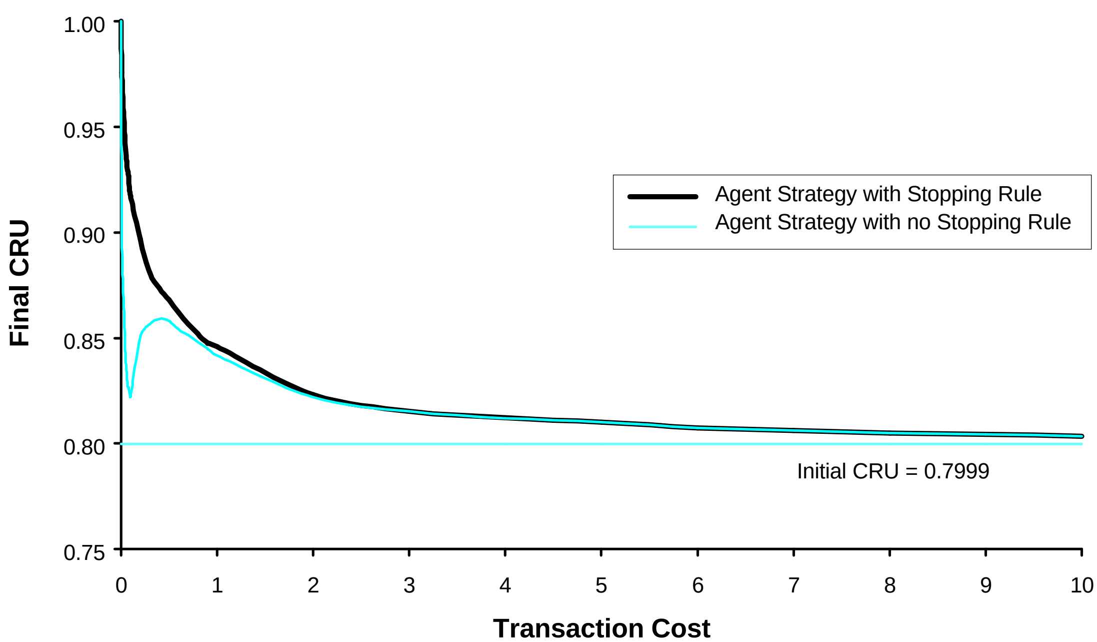
[15] The level of transaction cost that stops all trade varies from simulation to simulation, but is roughly equal to 35 units of goods X or Y.

Figure 4-1 Direct Trading: Evolution of CRU at Various Levels of TC (a)



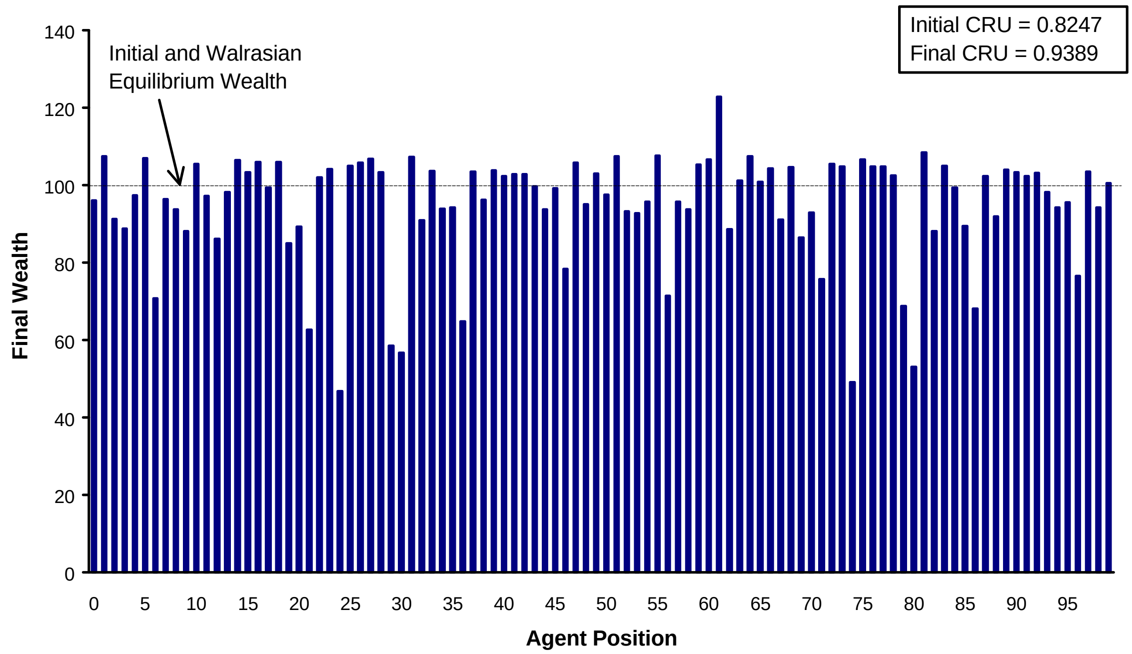
(a) Assumptions: Seed=31, TS=0.7, and Endowment = Ransom.

Figure 4-2 Direct Trading: CRU and Transaction Cost (a)



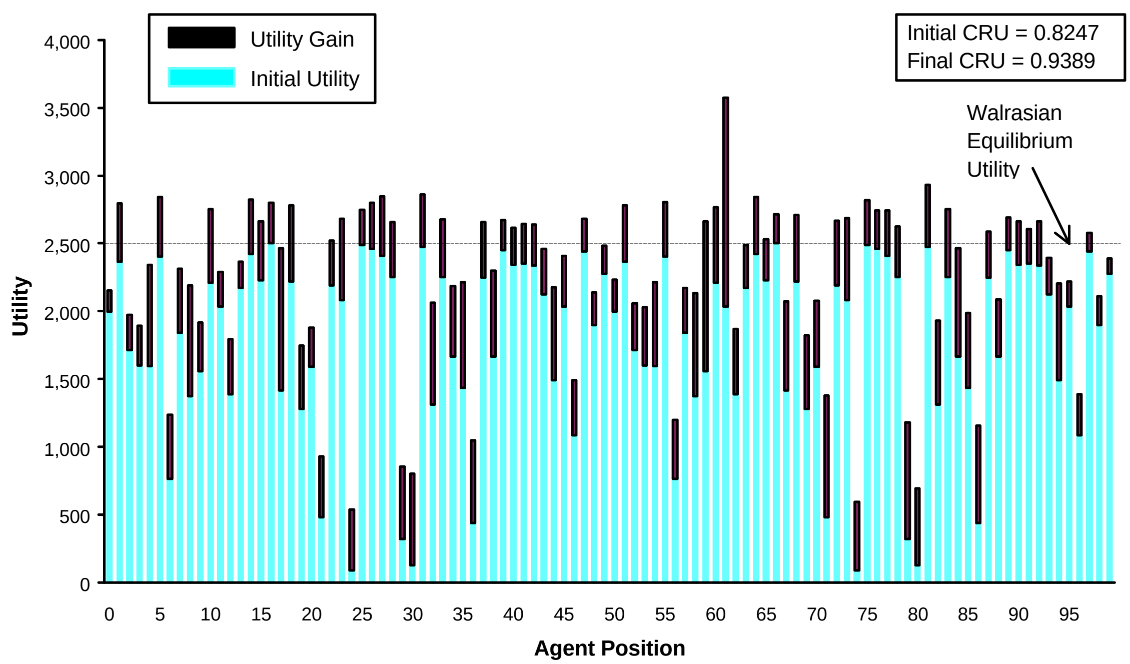
(a) Assumptions: Seed=31, TS=0.7, and Endowment = Random.

Figure 4-3 Direct Trading: Final Wealth of Agents(a)



(a) Assumptions: Seed=1, TS=0.7, TC=0.06, and Endowment = Random.

Figure 4-4 Direct Trading: Utility Gains of Agents(a)



(a) Assumptions: Seed=1, TS=0.7, TC=0.06, and Endowment = Random.

that a trade-off between information depreciation and transaction costs appears. As the number of trades are decreased by increasing transaction costs, the depreciation of information is reduced resulting in a positive relationship between transaction costs and the coefficient of resource utilization. Interestingly, as transaction costs become relatively high compared to the trade step, the two strategies' performances coincide implying that informational problems do not arise at high transaction costs.

Figures 4-3 and 4-4 show the actual final wealth and utility levels achieved by all the agents on the circle. In this particular simulation, the transaction cost was equal to 0.06 and the endowments of the agents were randomly distributed. The coefficient of resource utilization increased from 0.8247 to 0.9413. Initially all agents' wealth was equal to 100 as shown by the dotted line across Figure 4-3. Although several agents' wealth increased beyond 100, the gains were small as compared to the losses of some of the agents who lost wealth. But the agents that lost a great deal of wealth happened to be the agents initially endowed with extreme amounts of good X or Y. Such agents like agents 24, 29 and 30 who lost a great deal of wealth can be seen in Figure 4-4 to have made significant utility improvements as a result of trade after having started with very low levels of utility. Agents that saw their wealth increase as a result of trading also were the ones that attained utility levels greater than Walrasian equilibrium level.[16]

The effect of trade on the agents' marginal rates of substitution is shown in Figure 4-5. The top half of Figure 4-5 shows the initial distribution of the log of the marginal rates of substitution of the agents. Trade in a Walrasian economy would equalize the agents' marginal rates of substitution. Direct trading achieves a substantial amount of equalizing as seen in the bottom half of Figure 4-5 showing the final distribution of the log of the marginal rates of substitution of agents.

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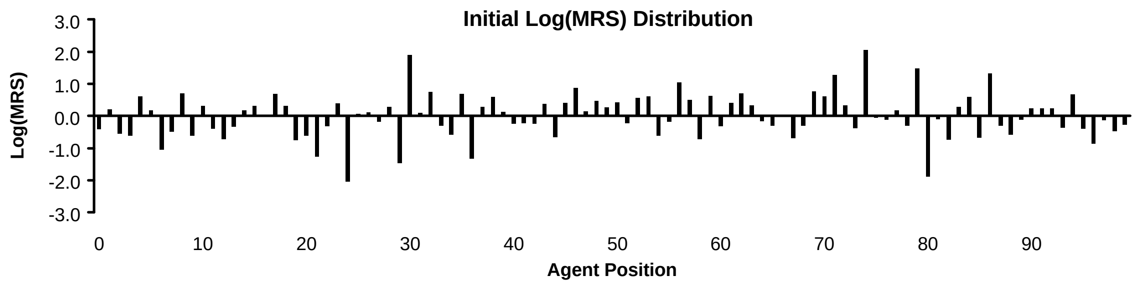
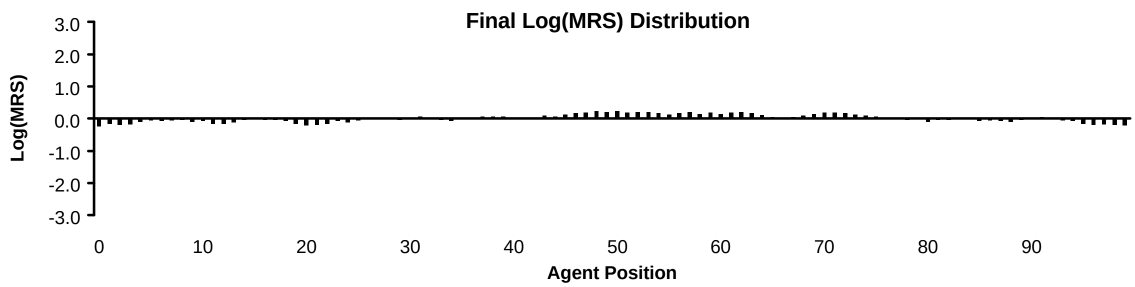
[16] Of course, it is possible for an agent to have wealth greater than Walrasian equilibrium without having her utility exceed that level , but that is not observed.

Figure 4-5 Direct Trading: Initial and Final Log(MRS) (a)





(a) Assumptions: Seed=1, TS=0.7, TC=0.06, Endowment = Random.

Close examination of the final distribution shows a small wave of the log of the marginal rate of substitution. Presumably there still might be gains from trade to be had from trade between agents in a frictionless world, but the opportunities are too small and far apart to merit continued trading given the level of transaction costs in this model.

Indirect Trading

This section contrasts the above results with results from the indirect trading protocol. Many of the qualitative results are similar, but a few significant differences arise from the type of increasing returns derived from trade because transaction costs are only incurred for the most distant agent visited.

The results of a typical simulation with indirect trading are shown in Table 4-5. As in Table 4-4 which show the direct trading protocol simulation results, trade improves the efficiency of the economy with the coefficient of resource utilization increasing from 0.8247 to 0.9532. Trading, however, is much more intense both in that the number of visits is more than double the number of actual trades and in that all trading opportunities are exploited in the first round of trading. A slightly smaller percentage of wealth is consumed in transaction costs than in the direct trading protocol as most of the trades occur at no cost. As in direct trading, average wealth decreases, and average utility increases, but inequality as measured by the standard deviation of wealth and utility both increase in this case. The average informational error and the average maximum distance traveled are both larger with indirect trading at the given level of transaction costs.

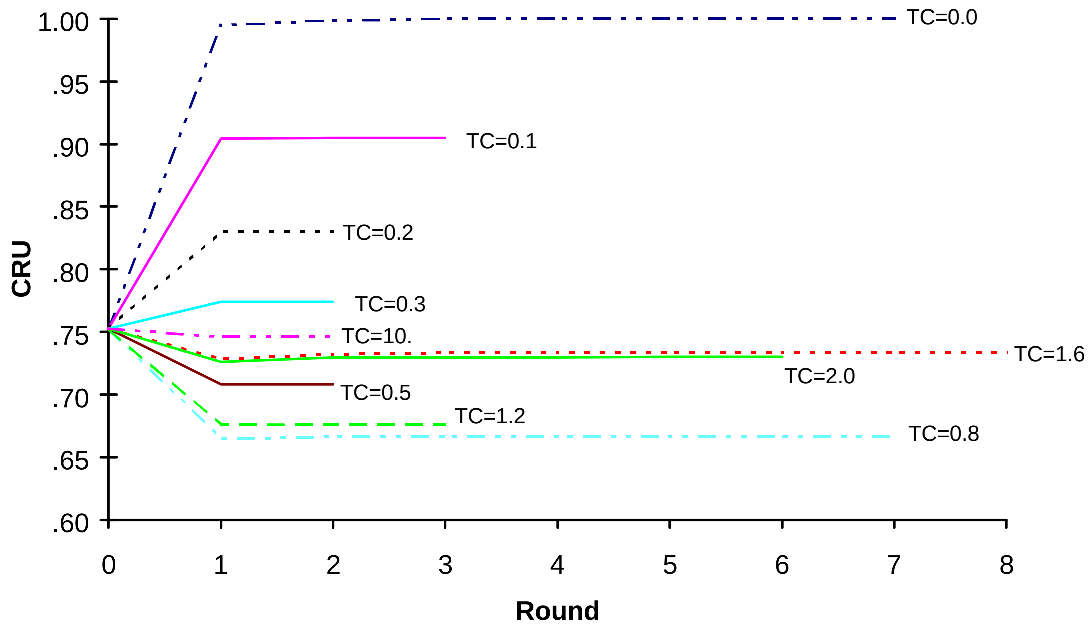
Table 4-5 Indirect Trading Simulation Results for TC=0.05 (a)

Round	CRU	#Trades	#Visits	AvelogMRS	SDlogMRS	AveW	SDW	SkewW
0	0.8247	0	0	0.000000	14.2813	100.00	0	0
1	0.9532	4,322	9326	-0.000666	1.0057	95.34	15.97	242.47
2	0.9532	0	0	-0.000666	1.0057	95.34	15.97	242.47
Round	**%WLost**	**AveU**	**SDU**	**AveUGap**	**SDUGap**	**AveD**	**SDD**	
0	0	1,797.59	659.95	0	0	0	0	
1	4.66	2,334.53	774.18	980.38	475.25	93.26	15.43	
2	4.66	2,334.53	774.18	0	0	0	0	

(a) Assumptions: Seed=1, TS=0.7, Endowment = Random.

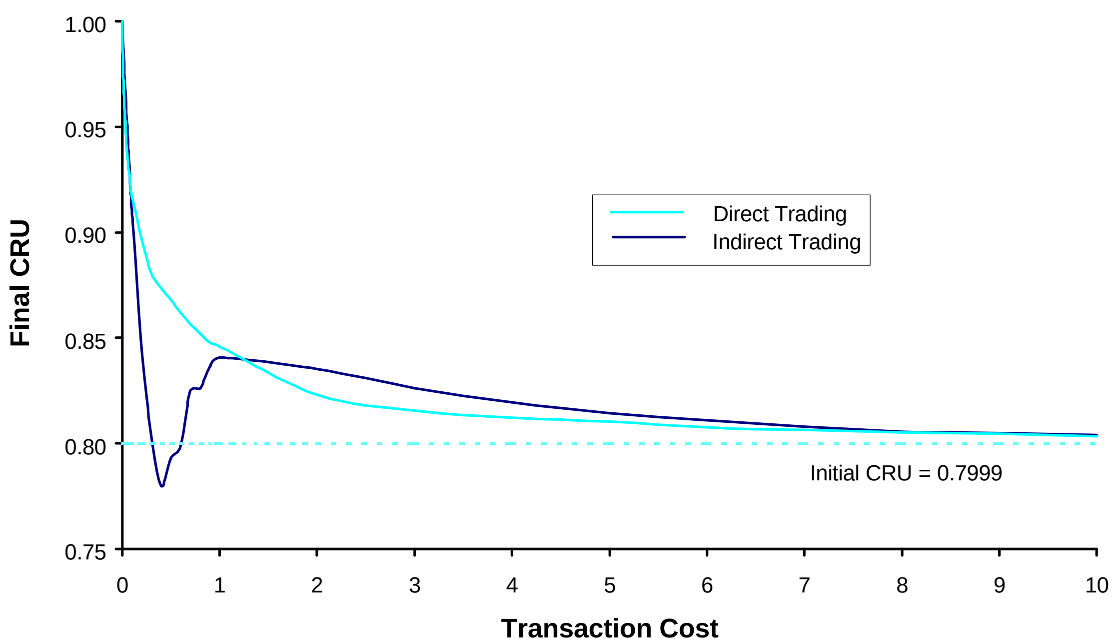
Figures 4-6 and 4-7 reveal a striking difference between direct and indirect trading. While the coefficient of resource utilization is basically negatively correlated with transaction costs, there is a range of transaction costs where higher costs actually improve economic efficiency. Also, for the beginning part of that range and before, the economy is made worse off by trade. Like the no-stopping-rule strategy in the direct trading protocol, this result is essentially due to agents being over-optimistic in their expected utility calculations. Because agents do not take into account or are unable

Figure 4-6 Indirect Trading: Evolution of CRU at Various Levels of TC (a)



(a) Assumptions: Seed=31, TS=0.7, and Endowment is Random

Figure 4-7 Direct and Indirect Trading: Final CRU and Transaction Cost (a)



(a) Assumptions: Seed=31, TS=0.7, and Endowment = Random.

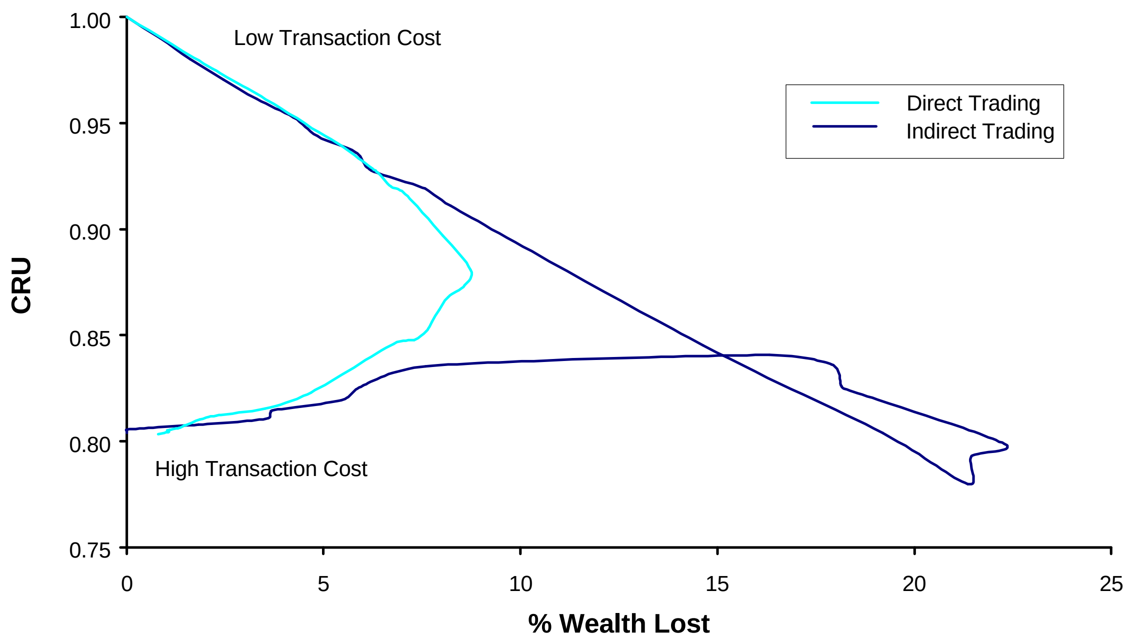
to take into account that the advertised marginal rate of substitution information changes as soon as agents begin a round of trading, agents will visit other agents whose marginal rates of substitutions have changed significantly from trade. But as transaction costs increase, agents are less likely to travel as far in an attempt to trade.[17] Thus, these informational errors are inadvertently reduced by higher transaction costs, leading to the non-monotonicity of the coefficient of resource utilization in transaction costs observed above.

The other striking result from Figure 4-7 is that despite the presence of a kind of increasing returns to transaction costs in the indirect trading protocol, there is a significant range of transaction costs where the direct trading protocol outperforms the indirect trading protocol. This result occurs where the indirect trading protocol suffers strongly from the effects of information depreciation and is reversed for higher levels of transaction costs.

Figure 4-8 attempts to level the playing field between the two trading protocols by comparing the performance of the two protocols as a function of the percentage of wealth lost. The figure shows the same data as in Figure 4-7 so that both series can be viewed as being mapped from Figure 4-7. Thus, the low transaction cost region in Figure 4-8 coincides with the beginning of both series on the left-hand side of Figure 4-7. As transaction costs are increased, the series move from the low transaction cost region to the high transaction cost region. It is interesting that the directing trading protocol does as well or better than the indirect trading protocol despite not having the benefit of the free visits of the indirect trading protocol. It is not clear whether this is a shortcoming in the candidate strategy for the indirect protocol or in the protocol itself.

[17] This is discussed in more detail below.

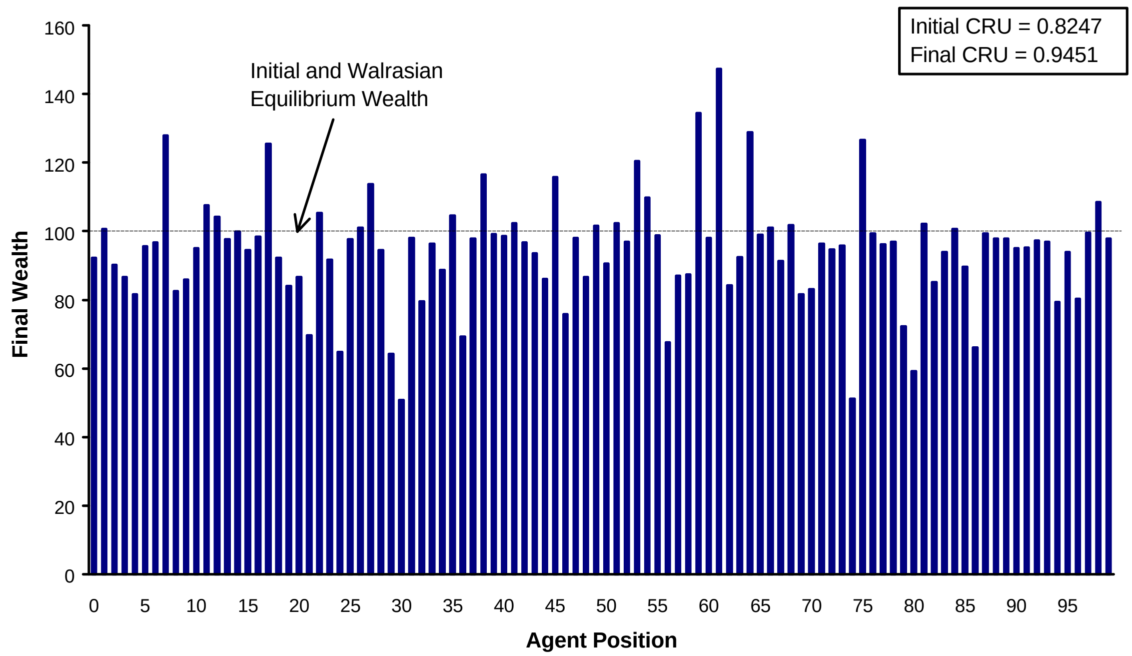
Figure 4-8 Direct and Indirect Trading: Final CRU and % Wealth Lost (a)



(a) Assumptions: Seed=31, TS=0.7, and Endowment = Random.

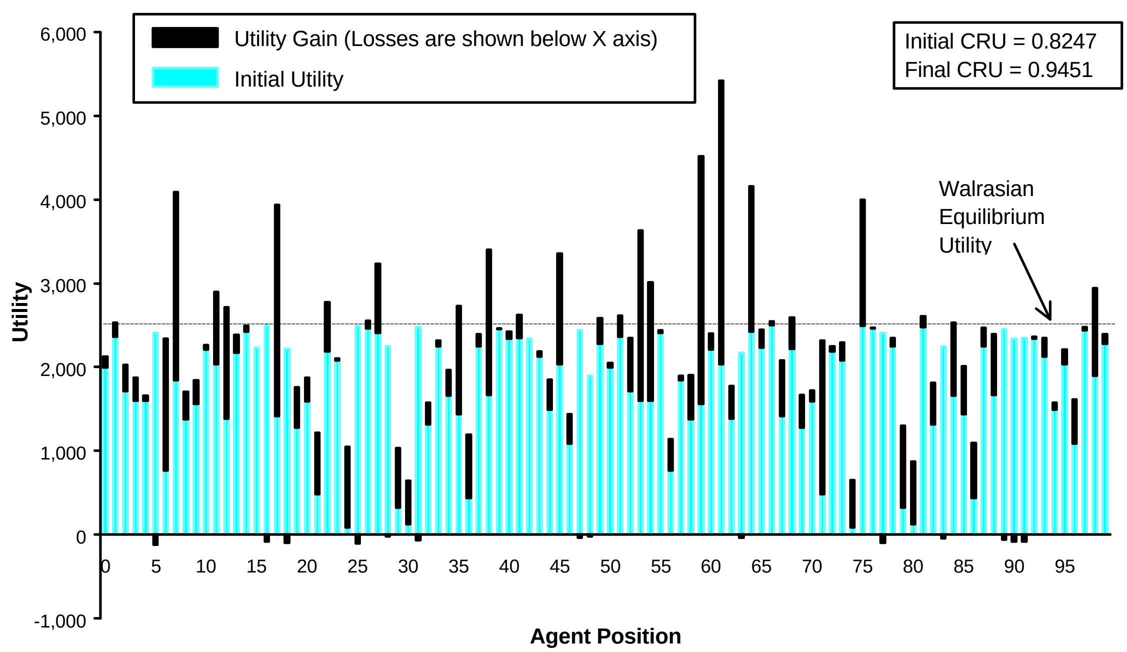
Figures 4-9 and 4-10 show the actual final wealth and utility levels achieved by all the agents on the circle. The transaction cost was equal to 0.06, well within the range of transaction costs where trade increases economic efficiency and where efficiency is decreasing in transaction costs. In this particular case, the coefficient of resource utilization increased from 0.8247 to 0.9451. Contrary to the direct trading case, several of the agents whose wealth increased enjoyed a substantial increase, while those agents losing wealth varied in the extent of their losses. The agents losing the most wealth were again those agents endowed with extreme combinations of X and Y. Agents whose final utility level exceeded the Walrasian equilibrium level of utility were the same agents that increased their wealth via trade.

Figure 4-9 Indirect Trading: Final Wealth of Agents (a)



(a) Assumptions: Seed=1, TS=0.7, TC=0.06, Endowment = Random.

Figure 4-10 Indirect Trading: Utility Gains (Losses) of Agents (a)

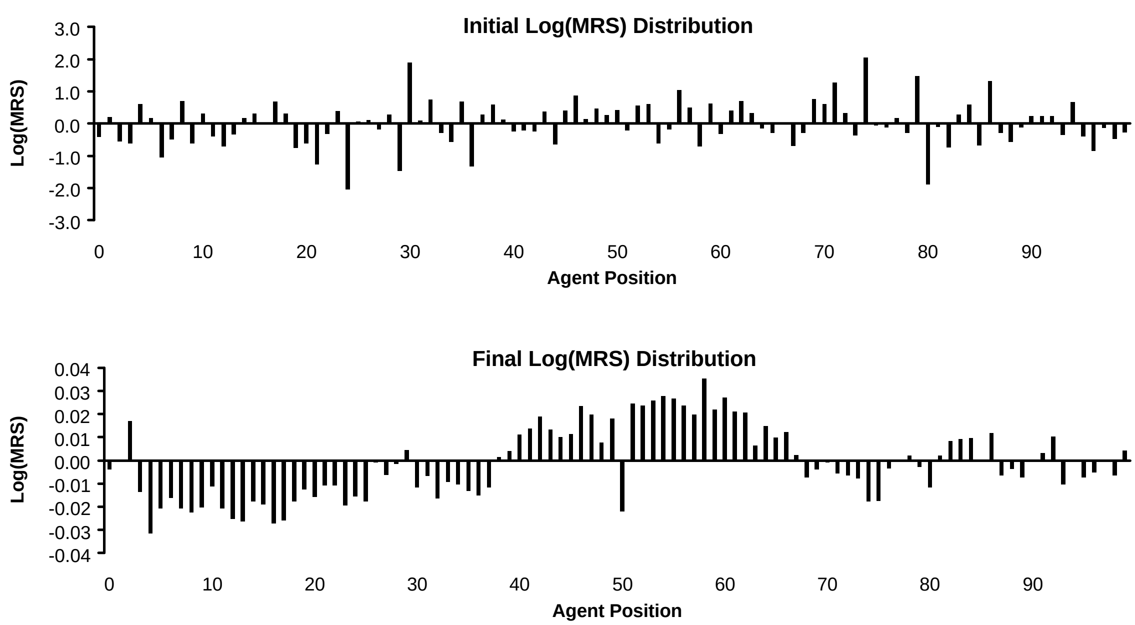


(a) Assumptions: Seed=1, TS=0.7, TC=0.06, Endowment = Random.

One final difference in Figure 4-10 as compared to Figure 4-4 is that there are agents that lost utility with indirect trading. The losses are shown below the X-axis and are generally very small in size. The losses are attributable to the informational errors described above where agents incur transaction costs in hopes of engaging in trade with other agents who no longer represent viable trading opportunities. This result means that the strategies used by the agents in indirect trading are not pareto-improving as some agents are actually made worse-off via trade.

The effect of indirect trading on the agents' marginal rates of substitution is shown in Figure 4-11. The initial distribution of the log of the marginal rates of substitution is shown in the top half of Figure 4-11, and the final distribution is shown in the bottom half.[18] As in direct trading, the log of the marginal rates of substitution are effectively equalized as a result of indirect trading.

Figure 4-11 Indirect Trading: Initial and Final Log(MRS) (a)



(a) Assumptions: Seed=1, TS=0.7, TC=0.06, Endowment = Random.

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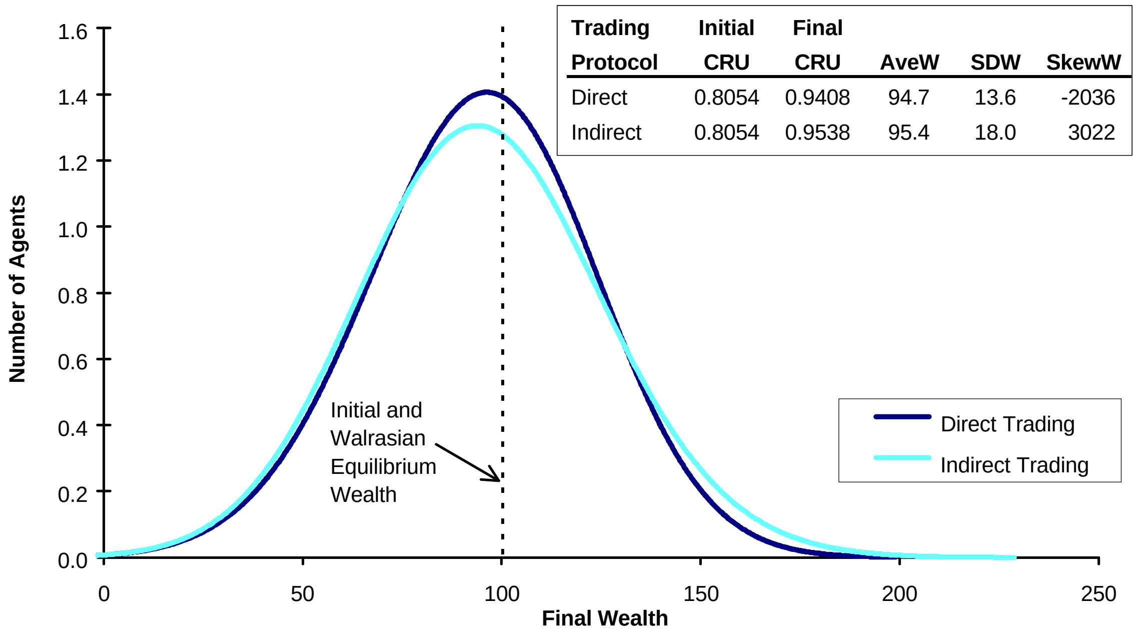
[18] The scale is changed on the bottom graph because the deviations from zero of the log of the final marginal rates of substitution are so small, the scale on the upper graph would reveal an "empty" graph.

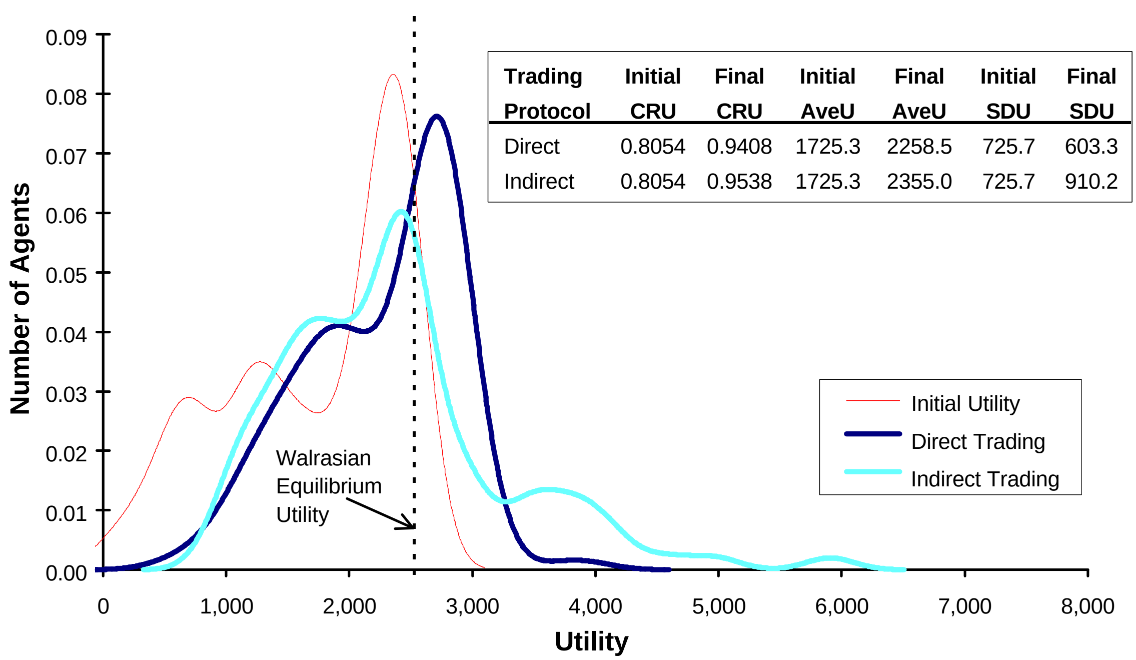
Figure 4-12 Direct and Indirect Trading Final Wealth Histograms (a)



Trading Protocol	Initial CRU	Final CRU	AveW	SDW	SkewW
Direct	0.8054	0.9408	94.7	13.6	-2036
Indirect	0.8054	0.9538	95.4	18.0	3022

(a) Assumptions: Seed=7, TS=0.7, TC=0.05, Endowment = Random.

Figure 4-13 Direct and Indirect Trading Final Utility Histograms



Trading Protocol	Initial CRU	Final CRU	Initial AveU	Final AveU	Initial SDU	Final SDU
Direct	0.8054	0.9408	1725.3	2258.5	725.7	603.3
Indirect	0.8054	0.9538	1725.3	2355.0	725.7	910.2

(a) Assumptions: Seed=7, TS=0.7, TC=0.05, and Endowment = Random.

Figures 4-12 shows histograms comparing the final wealth histograms for direct and indirect trading. The wealth histograms appear very similar, except that wealth is more unequal and slightly more skewed to the right in the indirect trading case. The difference in the standard deviation of wealth is not readily visible in Figure 4-12, but the marginally heavier right tail is. Both histograms are distributed fairly symmetrically around the Walrasian equilibrium level of wealth.

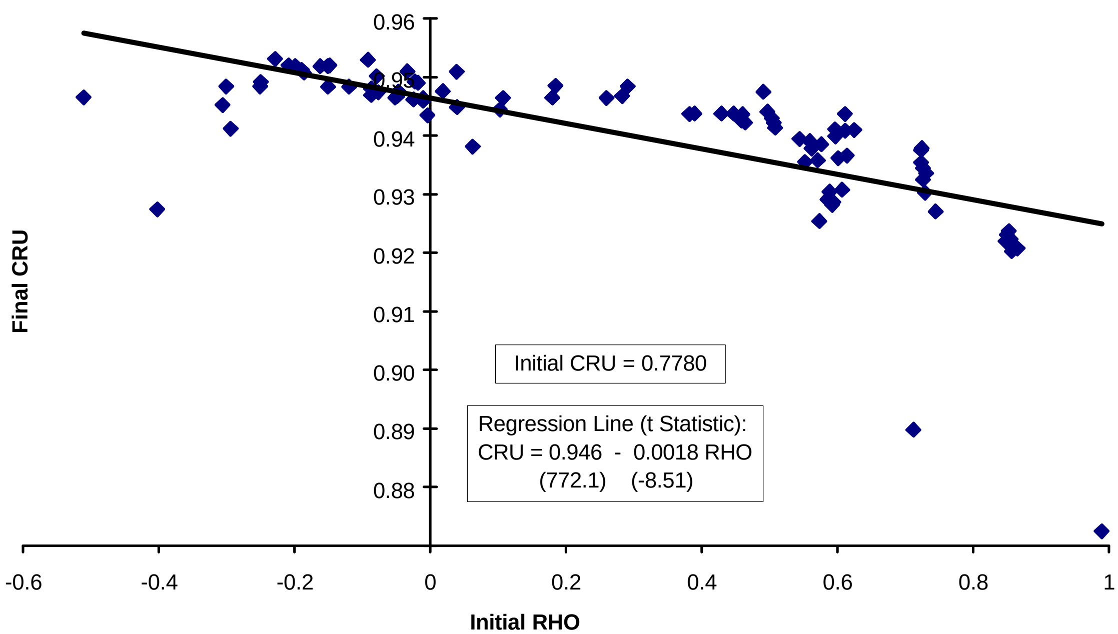
The effect of the slight increase in size of the right tail of the indirect trading wealth histogram results in a large difference in right tails of the utility histograms shown in Figure 4-13. Both histograms show a rightward shift relative to the initial utility histogram, but both trading protocols do not achieve the Walrasian equilibrium level of utility on average. As noted earlier, direct trading final utility is less unequally distributed than initially, but the inequality of utility increases for the indirect trading case.

Spatially Correlated Endowments

The initial allocations of goods X and Y have been randomly generated up to this point. This section examines the effects of rearranging these initial endowments to create various degrees of spatially correlated endowments on trade. The hypothesis is that an agent located in a highly concentrated region of agents with similar marginal rates of substitution will have to travel farther to find trade opportunities thereby decreasing the efficiency of the economy relative to the randomly generated endowment case.

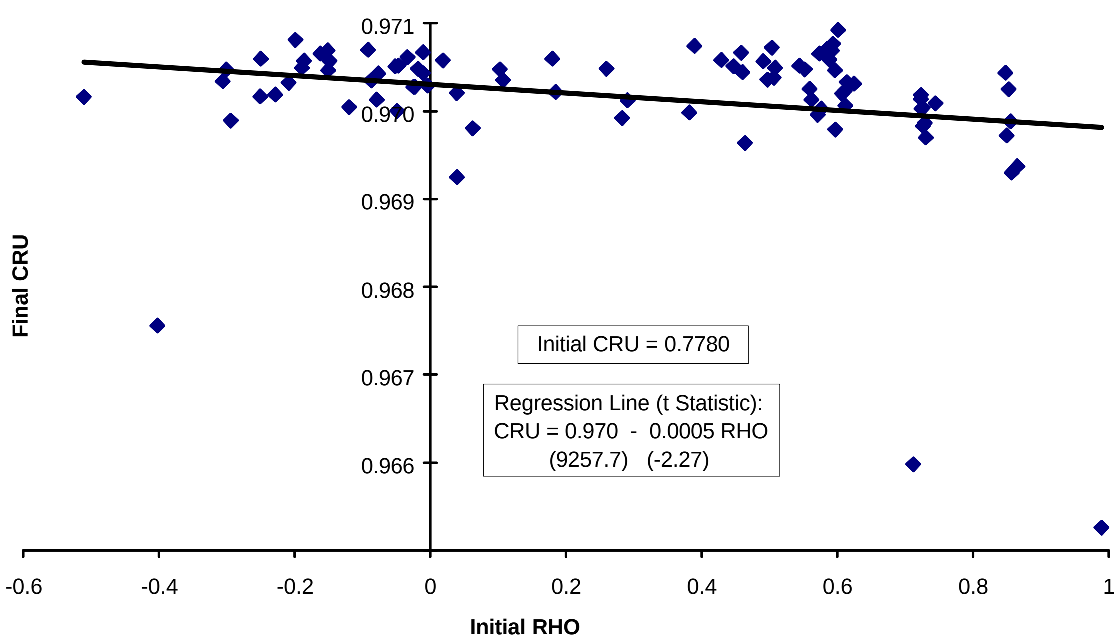
This hypothesis is somewhat supported by the data generated in both the direct and indirect trading cases. Figure 4-14 shows the effect of varying the degree of spatial correlation as measured by rho on the coefficient of resource utilization for the direct

Figure 4-14 Direct Trading: CRU and Spatially Correlated Endowments (a)



(a) Assumptions: Seed=27, TS=0.7, TC=0.03, and Endowment = Shifted.

Figure 4-15 Indirect Trading: CRU and Spatially Correlated Endowments (a)



(a) Assumptions: Seed=27, TS=0.7, TC=0.03, and Endowment = Shifted.

trading case.[19] A negative relationship between efficiency and spatial correlation is found.

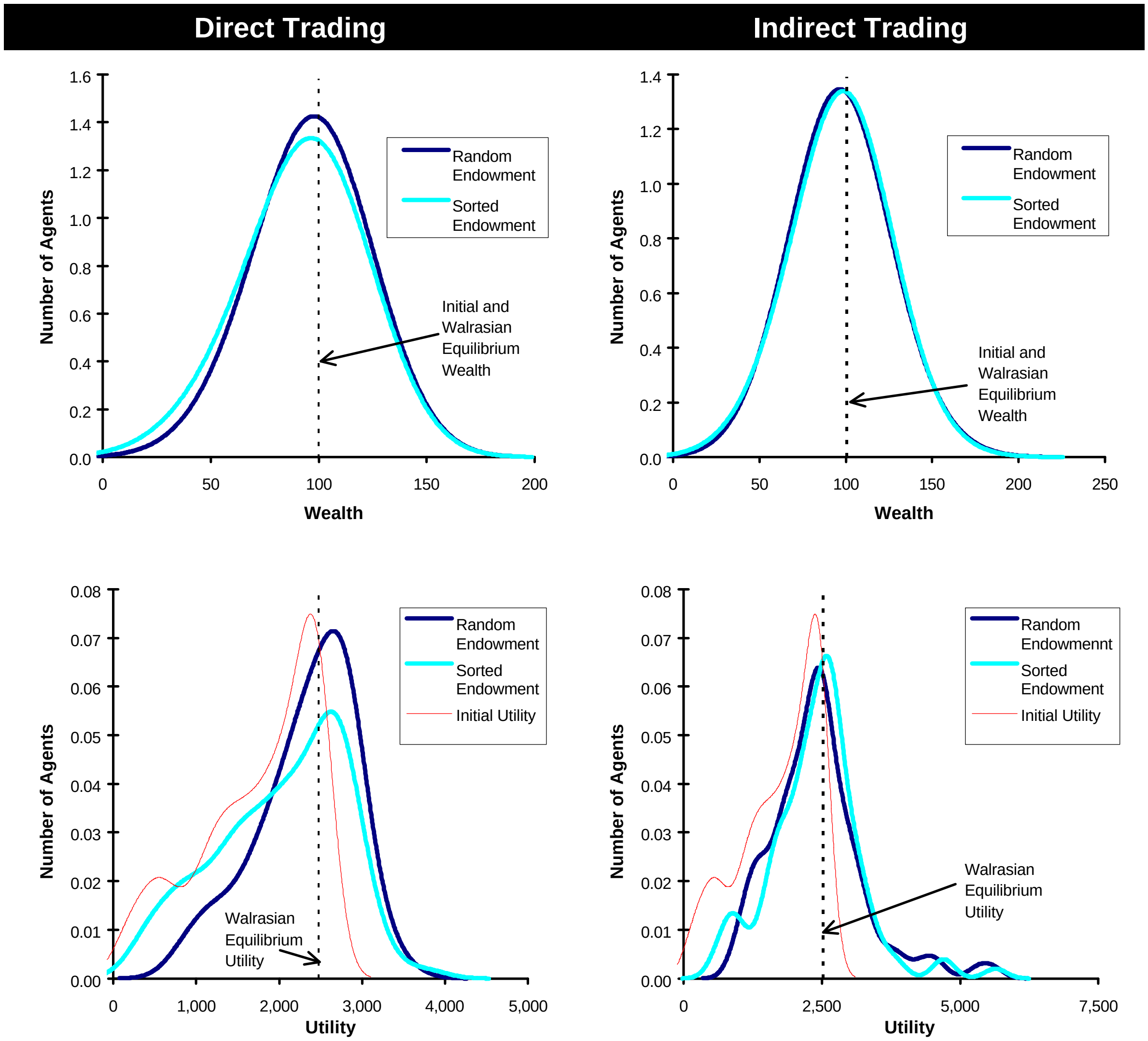
The case in Figure 4-14 where the initial endowment is sorted from highest to lowest marginal rate of substitution (Endowment = Sorted) is the outlier with rho almost equal to one. It is interesting that this initial endowment performs the worst of all the rearrangements of the initially randomly generated allocation. Presumably trade is so ineffective in the sorted endowment case because no nearby neighbors with significantly varied marginal rates of substitutions exist thereby forcing agents unequivocally to travel farther around the circle.

The relationship between the coefficient of resource utilization and the degree of spatial correlation is no longer negative for the indirect trading case shown in Figure 4-15 as the coefficient of the slope term is not statistically significant. This is probably because agents in the indirect trading case travel very far around the circle to trade regardless of the availability of trades in the immediate neighborhood of agents, whereas in the direct trading case, every agent visited makes a difference in terms of transaction costs paid. Still, one would expect that as transaction costs became higher, the degree of spatial correlation would become more important in indirect trading as agents did not travel as far from their home positions. Also, as in the direct trading case, the sorted endowment outlier in Figure 4-15 exhibits a marked decrease in the final coefficient of resource utilization as compared to the other rearrangements of the initially randomly generated endowment.

A comparison between the extreme cases of a randomly generated endowment and the same endowment sorted by marginal rates of substitution is given in

19 Slope coefficients and t-statistics are reported in Figures 4-14 and 4-15.

Figure 4-16 Spatial Correlation and the Distribution of Wealth and Utility (a)



(a) Assumptions: Seed=19, TS=0.7, and TC=0.03.

Table 4-6 Descriptive Statistics for Figure 4-16

Trading Protocol	**Initial CRU**	**Final CRU Random**	**Final CRU Sorted**	**Initial AveW**	**Final AveW Random**	**Final AveW Sorted**	**Initial SDW**	**Final SDW Random**	**Final SDW Sorted**
Direct	0.8113	0.9562	0.8799	100	96.2	92.6	0	13.0	17.5
Indirect	0.8113	0.9709	0.9650	100	97.1	97.0	0	16.7	17.5
Trading Protocol	**Initial AveU**	**Final AveU Random**	**Final AveU Sorted**	**Initial SDU**	**Final SDU Random**	**Final SDU Sorted**		**First Round AveD Random**	**First Round AveD Sorted**
Direct	1,744.4	2,327.4	2,026.4	702.4	580.5	771.4		8.8	7.7
Indirect	1,744.4	2,425.4	2,402.1	702.4	846.9	822.6		96.1	98.6

Figure 4-16. Supporting descriptive statistics are given directly below the figure in Table 4-6.[20] The effect of the sorted endowment is more readily apparent in the direct trading case. The wealth histogram of the sorted endowment simulation (average wealth = 92.6) is marginally shifted to the left relative to the random endowment run (average wealth = 96.2). As before, this slight shift in wealth histogram results in a much larger effect on the utility histogram. The sorted endowment utility histogram is noticeably shifted left. It is also more dispersed with a standard deviation of 771.4 compared to 580.5 for the random endowment case.

The effect of a high degree of spatial correlation in Figure 4-16 is not as obvious for the indirect trading case. Nevertheless, the coefficient of resource utilization does not increase by as much from trade as in the randomly generated endowment simulation. Final average wealth and utility are also lower. Nevertheless, the benefits of trade do not decrease as noticeably as in the direct trading case. One anomaly is that utility inequality from trade increases by less for the sorted endowment case than for the random endowment case even though the standard deviation of wealth does the opposite.

Figures 4-17 and 4-18 offer the sorted endowment equivalents of Figures 4-3 and 4-4, respectively. Just as in the simulations from Figure 4-16, the coefficient of resource utilization falls for the sorted endowment cases in both trading protocols. The effect on the coefficient of resource utilization is more striking for the direct trading case with the final coefficient of resource utilization falling from 0.9413 in Figure 4-4 to 0.8461 in Figure 4-16. The difference in efficiency is evident in the fewer number of agents exceeding the Walrasian equilibrium level of utility in Figure 4-17 as compared to Figure 4-4. Also noteworthy is that the sorted endowment causes many agents to

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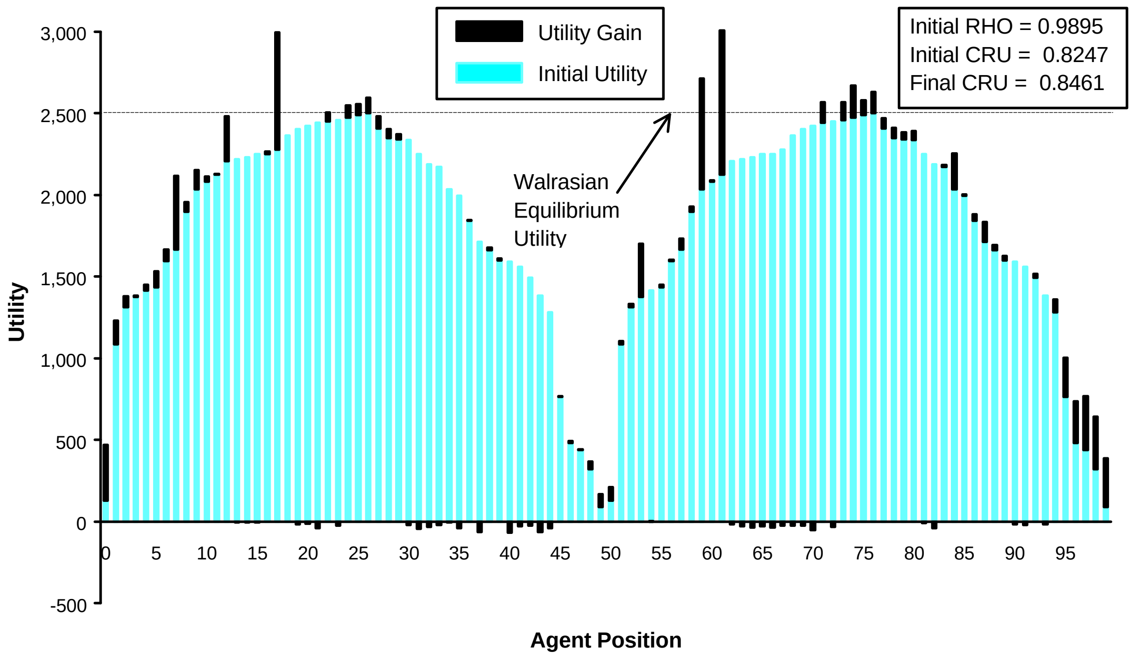
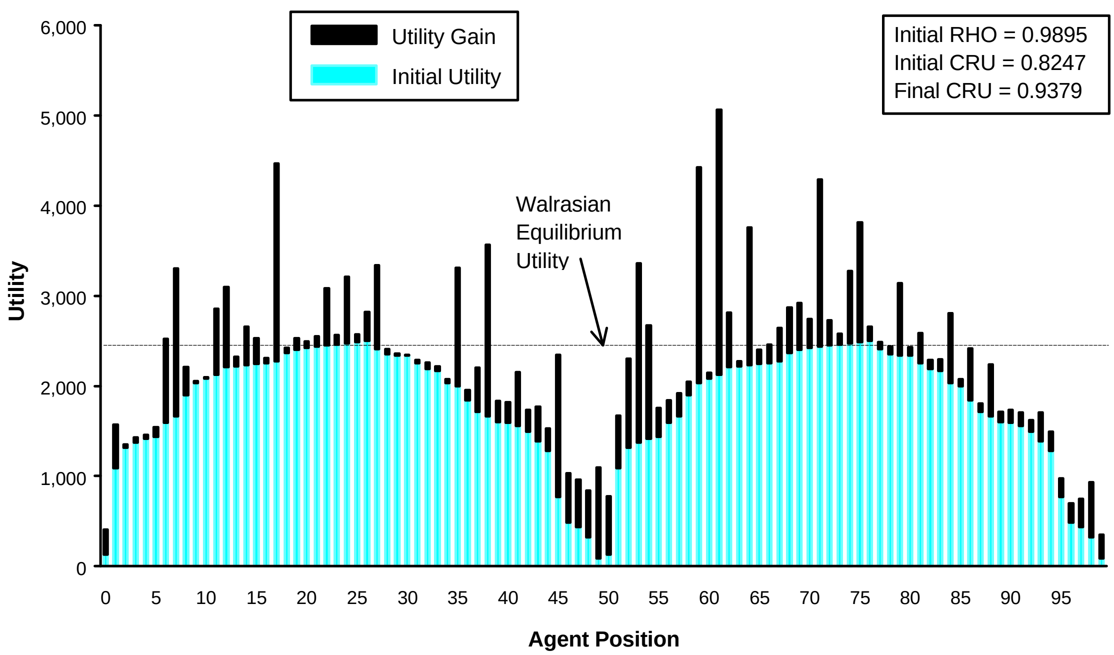
[20] The average maximum distance traveled (AveD) listed in Table 4-5 is discussed in the next section.

Figure 4-17 Direct Trading: "Sorted" Utility Gains (Losses) of Agents (a)



(a) Assumptions: Seed=1, TS=0.7, TC=0.06, Endowment = Sorted.

Figure 4-18 Indirect Trading: "Sorted" Utility Gains of Agents(a)

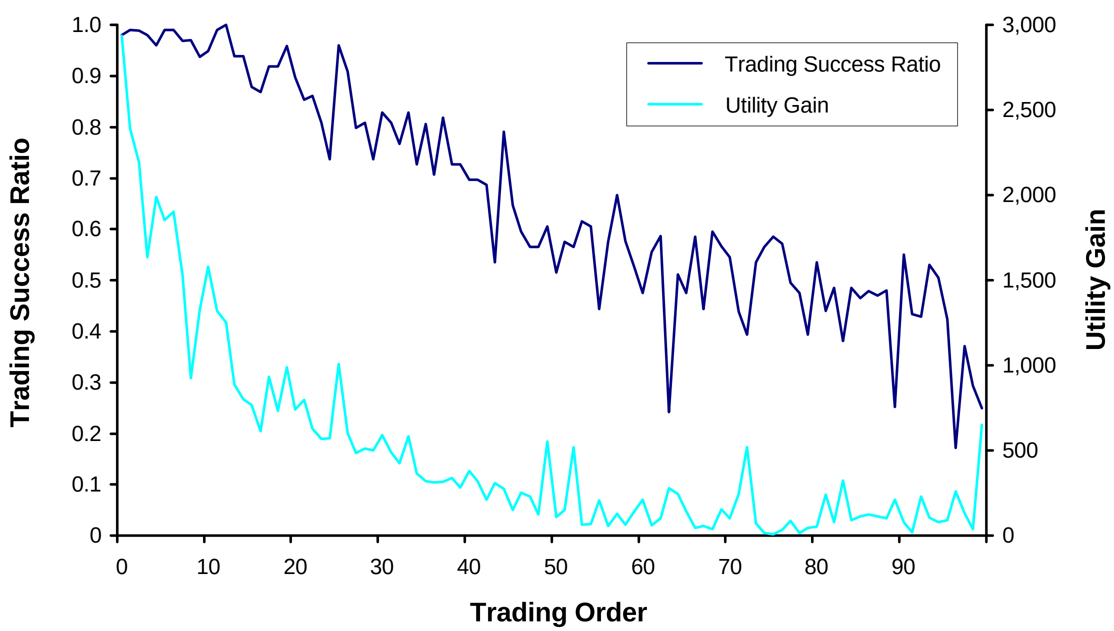


(a) Assumptions: Seed=1, TS=0.7, TC=0.06, Endowment = Sorted.

suffer losses in utility as a result of trade which was unobserved before.

The fall in the final coefficient of resource utilization from 0.9451 to 0.9379 in the indirect trading case is much smaller than in direct trading. The final coefficient of resource utilization falls despite the fact that there are no utility losses in Figure 4-18.[21] There are five agents in Figure 4-17, however, who are able to make incredible utility gains giving them final utilities above the 5,000 level compared to only one agent in Figure 4-10 achieving this feat. The increase in the number of extremely utility-rich agents is also observable in Figure 4-16 in the slight rightward shift of the right tail of the sorted endowment utility histogram.

Figure 4-19 Indirect Trading: The Importance of Trading Order (a)



(a) Assumptions: Seed=1, TS=0.7, TC=0.06, Endowment = Sorted.

The question of why certain agents benefit so much from trade in the indirect trading case is examined in Figure 4-19 which shows two series as a function of the trading order of agents. The first series is the trading success ratio which is defined as the ratio of the number of trades to the number of visits. As is evident from Figure 4-19,

21 This is in contrast to Figure 4-10 where indirect trading results in agents losing utility from trade.

those agents that engage in trade early in the round have a much greater success in trade as the trading success ratio falls continuously as trading order increases.

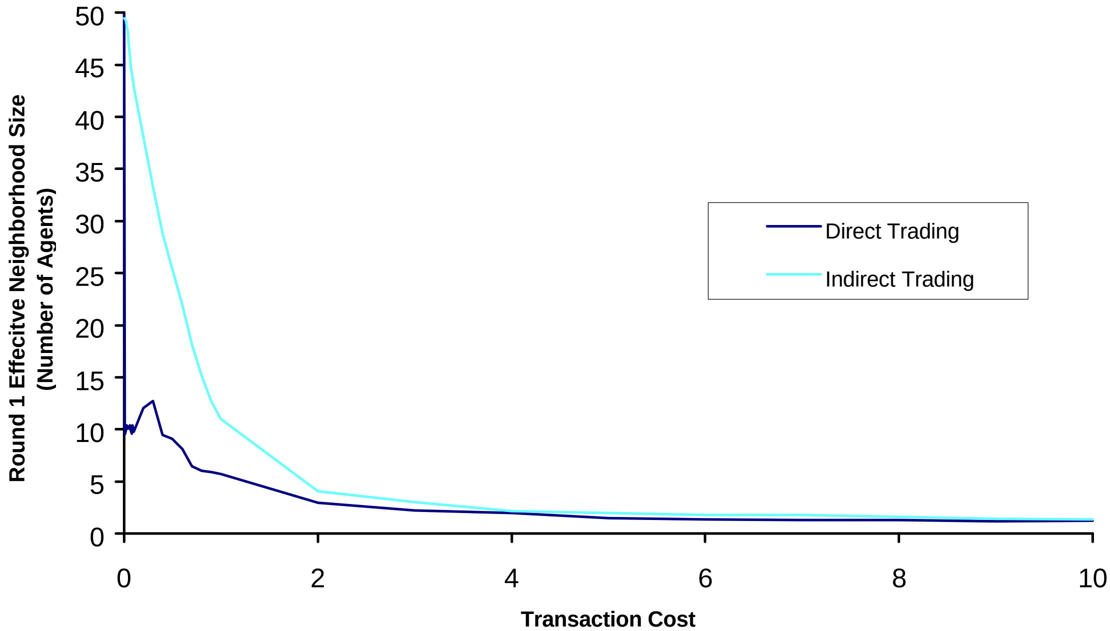
The second series in Figure 4-19 is the gain in utility from trade. It shows that the first few traders achieve by far the largest gains from trade. After roughly half of the agents have engaged in trade, the utility gains from trade are severely limited. In fact, it is probable that the gains that the late-trading agents experience derive from the trades resulting from agents visiting them rather than from trades resulting from the agents that they visit.

The notion that the agents that benefit most from trade are the ones that engage in trade early is also supported in the direct trading case by comparing Figure 4-17 with Figure 4-10. Such a comparison shows that the same agents in both scenarios benefit significantly more than other agents from trade. This indicates that the benefit comes not so much from the position agents have on the circle, but rather from the order in which they trade. The same comparison for the indirect trading case can be made between Figures 4-18 with Figure 4-11 with the same result.

Endogenous Neighborhood Size

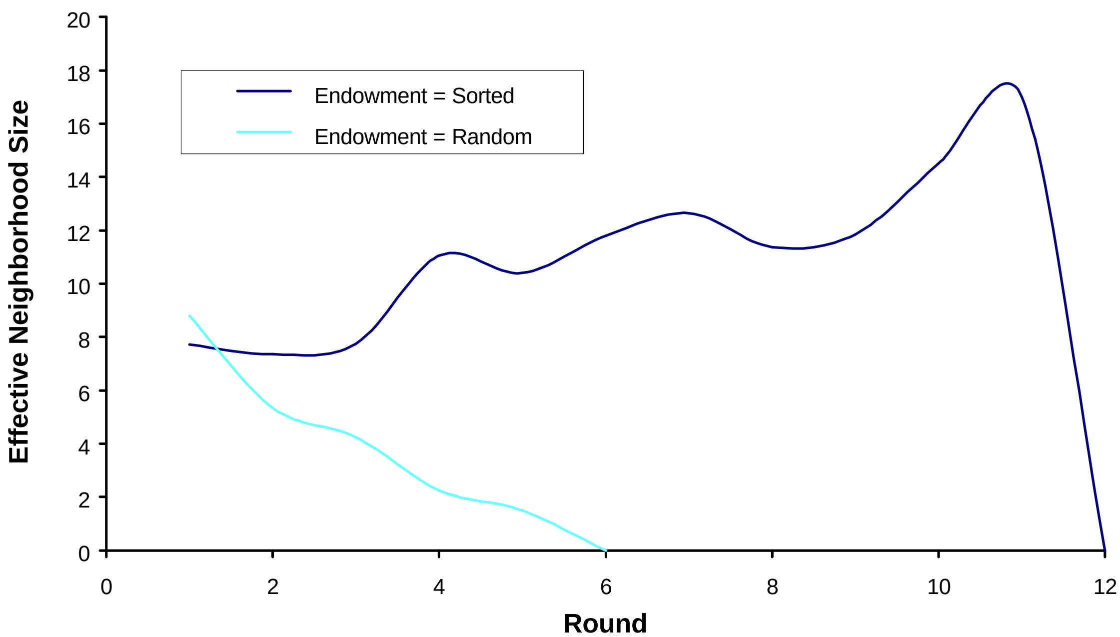
The neighborhood size of an agent is determined endogenously by each individual agent in this model. The effective neighborhood size under both trading protocols is shown in Figure 4-18 for transaction costs under 10. Note that the neighborhood size of an agent in the indirect trading case is defined to be one half of the distance traveled to the farthest agent visited, rather than a one-sided definition of

Figure 4-20 Effective Neighborhood Size and Transaction Costs (a)



(a) Assumptions: Seed=53, TS=0.7, Endowment = Random.

Figure 4-21 Direct Trading: Evolution of Effective Neighborhood Size (a)

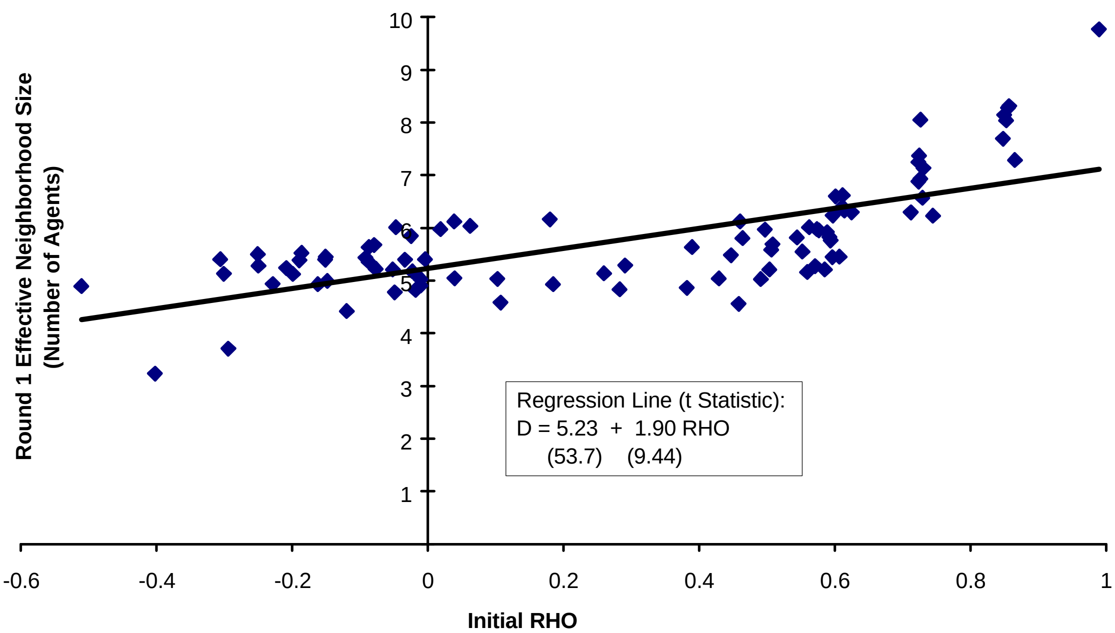


(a) Assumptions: Seed=19, TS=0.7, TC=0.03.

neighborhood size that would make it difficult to compare direct and indirect trading protocols. The effective neighborhood size is clearly decreasing in transaction cost for the indirect trading protocol, but for the direct trading protocol, the effective neighborhood size is decreasing in transaction costs only after a small anomalous region where increasing transaction costs actually cause agents to travel farther along the circle. This is probably as a result of the stopping rule which keeps agents from traveling too far from their home positions when transaction costs are so low that trade results in rapidly depreciating information. As transaction costs rise, the intensity of trade abates, and agents do not make mistakes as quickly and are able to venture out farther along the circle. The benefit transaction costs provide in decreasing informational errors, however, is soon outweighed by the loss of utility they produce, and from that point on, the effective neighborhood size is negatively related to transaction costs. Also evident from Figure 4-20 is that for every level of transaction cost, indirect trading has a larger effective neighborhood size than direct trading.

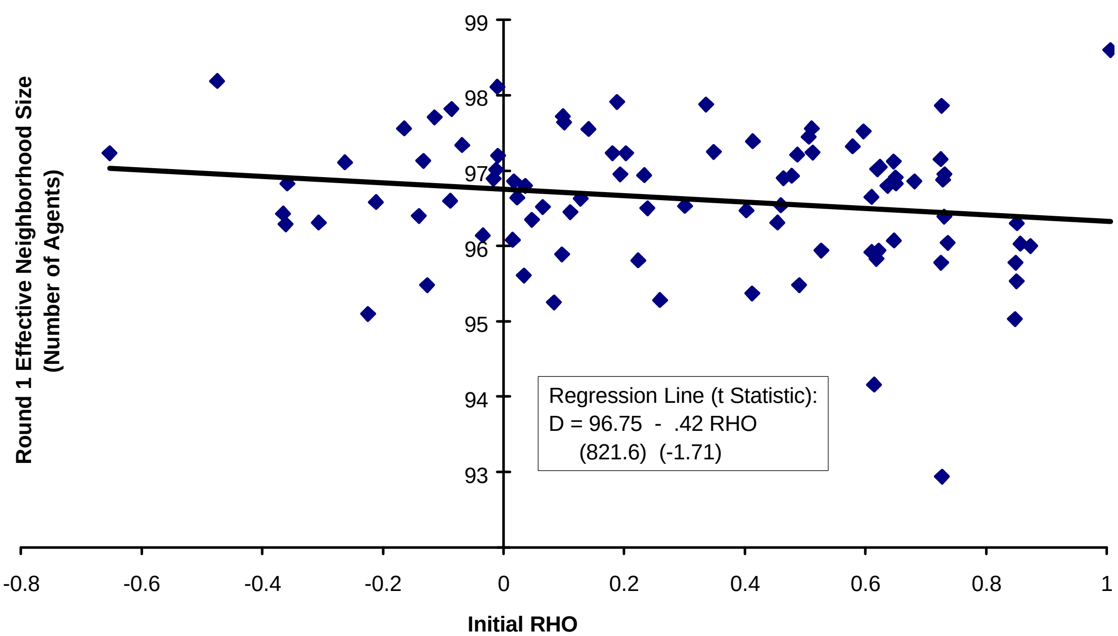
Figure 4-21 shows the time evolution of the effective neighborhood size for the direct trading protocol for the two extreme endowment cases at a low transaction cost equal to 0.03. Presumably, the stopping rule as discussed above stops agents from venturing out too far in the first rounds of trading in the sorted endowment case, but because the local trading opportunities are poor, as informational problems diminish in the later rounds of trading, the agents that venture out to trade must travel farther in order to find trading opportunities. The opposite behavior is observed for the random endowment case because local trading opportunities are available after the initial intense round of trade, and these are quickly exploited by nearby agents making long visits unproductive.

Figure 4-22 Direct Trading: Effective Neighborhood Size and RHO (a)



(a) Assumptions: Seed=27, TS=0.7, TC=2, Endowment = Shifted.

Figure 4-23 Indirect Trading: Effective Neighborhood Size and RHO (a)



(a) Assumptions: Seed=19, TS=0.7, TC=0.03, Endowment = Shifted.

Figure 4-22 shows the effect of spatially correlated endowments on the first round effective neighborhood size in the direct trading case. As was hypothesized earlier, agents find they have to travel farther in the highly spatially correlated endowment cases in order to find agents on the other side of the market. The sorted endowment case once again gives the maximum effective neighborhood size.

Figure 4-23 shows the effect of spatially correlated endowments on the effective neighborhood size in the indirect trading case for the same initial conditions as in Figure 4-16. Although the regression line shows a slight positive relationship between the maximum distance traveled and the degree of spatial correlation, the slope coefficient of rho is not statistically significant at the 5% level. Thus, the seemingly anomalous result from Table 4-6 showing a decrease in distance traveled for the sorted endowment case as compared to the random endowment case is attributable to chance, and no relationship between effective neighborhood size and spatial correlation is found for the indirect trading case.

5. Conclusion

The main result of this study is the existence of a negative search externality that results in over-trading at low transaction costs. This result occurs in both trading protocols modeled, but economic efficiency only suffers in the indirect trading protocol where no stopping rule can be implemented. The importance of the stopping rule in mitigating this externality in the direct trading protocol trading strategy suggests that the way boundedly rational strategies are modeled strongly affects the over-trading result. In this study, agents do not question the accuracy of the advertised information. An alternative to this approach would be to model agents' belief regarding the accuracy of the advertised information parametrically so that there would be a continuum of agent types ranging from agents that believed that information was completely undepreciated as modeled herein to those that believe it was fully depreciated.[22] The parameter could be a function of the number of visits that the agent has observed so that the agent could pursue different strategies depending on how early in the trading round she believes she is trading. If agents' beliefs resembled the latter extreme, it is quite possible that a positive search externality or under-trading would result at all levels of transaction costs.

In this study, truthful disclosure was assumed on the part of agents, yet informational distortions still arose as a result of the trading process. The problem of asymmetric information could severely restrict market participation as agents conceivably would not believe the advertised marginal rates of substitution even before taking into account the above possibility of depreciated information. This problem poses new difficulties for the modeling process since beliefs would be required for every agent

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[22] Agents' beliefs could be represented by a parameter, $0 \leq b \leq 1$, such that agents believed that the true marginal rate of substitution was equal to $MRS^{1 \pm b}$ instead of simply MRS. In the case modeled above, b=0. The sign in front of b would be depend on whether agents believed the marginal rate of substitution was above or below what agents believed was the equilibrium price. In the case where b=1, agents would approximately believe that there were no trading opportunities available.

that advertises. In the context of a repeated version of this model, truthful disclosure could result if reputation was important.

The importance of beliefs in determining outcomes in models of this type does not simply imply that everything is possible. Indeed, at moderate to high transaction costs, no over-trading occurs even in the simplest case where agents trust the accuracy of the advertised information modeled herein. Rather, it suggests the importance of economic institutions that promote truthful advertising and disclosure, as well as the importance of transaction costs in encouraging trade to be restricted to smaller neighborhoods. If transaction costs are high enough to encourage small neighborhood sizes, then arguably agents will gain greater knowledge of the agents within their neighborhood, which would mitigate the types of informational problems that arise in this study.

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