Self-organizing Production and Exchange

by

Allen Wilhite
Department of Economics and Finance
University of Alabama in Huntsville
Huntsville, AL 35899
(256) 890-6590 phone
(256) 890-6328 fax.
wilhitea@email.uah.edu
homepage -- http://cas.uah.edu/wilhitea/

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preface

As will soon be obvious to the reader, this research project is in its early stages. One of my long-term interests is the emergence of social structures. Economists have some explanation as to the purpose of firms (to economize transactions costs), governments (to define property rights and provide public goods) and other social structures, but how do such organizations arise? More succinctly, under what conditions can we expect to see a group of autonomous agents self-organize to create social and economic structures? The following is but a small step toward finding out.

abstract

Consider a simple economy in which autonomous agents are endowed with two goods, g_1 and g_2, and with the capability of producing more of each. At regular intervals each agent is allowed to produce one of the goods, at a rate determined by his own unique production function, or to trade with other agents in the economy. The opportunity cost of each activity is the inability to pursue other activities; that is, if an agent decides to produce good 2, he cannot produce good 1 or initiate trade with other agents in that time period. Each good also yields utility for the agents according to a utility function with the standard first and second derivatives. This paper studies how utility-maximizing agents optimize in these circumstances, examines the aggregate characteristics of the economy, and investigates the internal organization of production and exchange.

Given this simple structure, our agents display an assortment of behaviors. A common outcome is for some agents to produce one good and trade for the other. Other agents, however, specialize further. For example, one agent may be highly proficient in the production of g_1. If he is "discovered" by other agents as a ready source of g_1, he may elect to produce in practically every period and trade for g_2 at someone else's initiative. Other agents specialize in trade. These "merchants" produce rarely, or not at all, choosing to buy in one period and sell in the next.

We also explore this system with agents who have a bit of memory and the ability to learn trade protocols that allow them to reduce their transactions costs. In those cases we also see agents specializing in their customers, that is, establishing long-term trade relationships with a few specific agents in the economy.

Self Organizing Production and Exchange

Production and trade lie at the root of economics and much of what economists do consists of explaining how, and how well, a society accomplishes those fundamental objectives. Since Adam Smith's pin factory economists have studied the effects of specialization, the division of labor, and the invisible hand that seemingly guides this organization. This paper continues that old tradition using a new and still emerging methodology.

Herein an artificial economy is constructed in which autonomous agents deal with production and exchange. This computer generated environment is then manipulated and the agents' choices and the consequences of those choices are observed. Albin and Foley (1992) used a similar approach to study a pure exchange economy (similar to the model in section 2 below) and found that a decentralized market quickly attained a Pareto efficient price vector. Vriend (1995) set up a system of buyers and sellers, gave them a method of communicating, and studied the characteristics of the emerging markets. And, several investigators have concentrated on the geographical aspect of trade by studying trade networks in which a specific topology is introduced to the system or in which agents evolve their own trade topology. These include studies by Ioannides (1997), Kirman, Oddou, and Weber (1986), and Epstein and Axtell (1996).

In this study we consider an economy in which artificial agents have the ability to produce one of two goods and can trade those goods among themselves. Constrained by time, agents can only take one action each period, that is, they can produce one of the goods or trade for one. We are interested in both the macroeconomic and microeconomic consequences of these choices. Even though the choices are simple, each agent just tries to improve his or her situation, we see a variety of strategies adopted by these agents and we also witness the emergence of some organizational structure in the artificial society. Specifically, many agents specialize in production or in trade. A subset of those specializing in production specializes further by concentrating on the production of a single good. And, when agents have a bit of intelligence they form long-term relationships with a select few of the other agents in the economy.

A Model Economy

In this paper we build a simple economy with only two goods. These are durable goods in the sense that they survive and suffer no real depreciation (no degradation) during the experiment. Both goods have value as an intrinsic source of pleasure and as a durable asset to be used in exchange. Examples might be books, toys, works of art, precious stones and other collectibles. One of the goods, g_2, is infinitely divisible but the other, g_1, must be traded in whole units.[1]

In this artificial economy n agents vie for the possession of these goods to maximize their utility according to a symmetric Cobb-Douglas utility function. Agents are initially endowed with a randomly determined allocation of each good and, depending on the experiment being studied, they can trade these goods among themselves or produce more of each according to their own, unique production function. Agents are rational, non-strategic, and myopic in that they do not attempt to mislead potential trade partners, nor do they plan for future opportunities. They simply try to improve their current position in each period by producing one of the goods or by engaging in voluntary trade.

The utility of agent i, U^i, depends on the amount of the two goods, g_1 and g_2 he possesses according to the following utility function:

$$(1) \qquad U^i = g_1^i \, g_2^i, \qquad i \in \{1,\ldots,n\}.$$

Each agent's ability to produce good 1 and good 2 is predetermined by a simple production function whose capacity is set at the beginning of the experiment and fixed throughout.

$$(2) \quad \Delta g_1 = r^i; \quad \Delta g_2 = s^i \qquad r, s \in \{1,\ldots,k\}; \; i \in \{1,\ldots,n\}$$

where r and s are randomly determined integers lying in the range of 1 to k.[2]

[1] Requiring increments of a whole unit of good 1 adds some rigidity (and realism) to the model. The effects of this rigidity were explored by altering the aggregate initial endowment.

[2] The simulations reported here set n=100, k=30, initial endowments range from 1 to 60 and the number of rounds equals 100.

Each period agent *i* is able to produce r^i amount of good 1 or s^i amount of good 2, if he chooses to produce. The only costly input into production is the agent's time in the sense that if an agent decides to produce good 1, he cannot produce good 2 or trade. For example, suppose the economy's goods are toys and precious stones. Production involves an agent taking his or her time to make toys out of readily available materials or to harvest precious stones perhaps from some nearby, commonly held mine. Each agent's unique production capabilities may reflect his or her proficiency at production, or location in a particularly rich environment. If it is location that affects production, the agents in some sense don't realize it because there is no movement to exploit locational advantages. Thus the agents' production functions are set at the beginning of the simulation at a per period rate and remain unchanged during the experiment.

Experimental Design

We proceed by comparing the performance of these artificial agents under several different sets of circumstances involving the type of economy under consideration and the intelligence of the traders. Three types of economic systems are studied: (i) a pure production economy (a self-sufficient economy in which agents produce only for themselves) (ii) a pure exchange economy with no production and (iii) an economy in which agents can produce or trade although they are limited to one activity in each round. In each regime we study low intelligence agents defined as agents with no memory and no ability to learn and high intelligence agents defined as agents with limited memory and the ability to learn specific trade protocols so that repeated trade with familiar partners becomes less costly. The intersection of these attributes creates six environments as shown in Table 1. We shall see, however, that in two cases intelligence has no impact on the system's performance, thus, there are only four distinct economies.

insert Table 1 about here

We are interested in the aggregate or macroeconomic performance of these economies as well as the microeconomic decisions made by individual traders. At the micro level we are particularly interested in emergence of any organizing behavior among agents and the circumstances under which such organization arises. The general procedure will be to create an artificial population and study its performance in each situation, then to create another population and repeat the experiments. At this stage of the project ten different populations have been placed in these situations.

Production and Trade in Artificial Societies

I. A Primitive Society: pure production and no trade;

A. low intelligence agents

Suppose sole activity of the members of this society is production, that is, they engage in no trade. This is a primitive, self-sufficient society in which individuals survive as hunter/gatherers. The constraint on these individuals is that they can produce only one good in each time period. They must choose. Thus, in every round agents calculate their utility if good one is produced and their utility if good two is produced and they simply pick the best alternative.

The resulting behavior in this primitive society is largely as one would expect. There is economic growth as agents produce in every round although the rate of growth declines over time because production is constant while wealth is increasing. Individual agents also behave as one would expect. In general, they switch their production from one product to the other in a pattern that maximizes their utility. If an agent's initial endowment was radically skewed to one of the goods, he may specialize in the other for a few periods because it yields greater marginal utility (the abundant good being further in the grip of diminishing marginal utility). But for the most part agents quickly fall into a pattern of switching their production from one good to the other. The frequency with which they switch their production depends on their relative productivity of each good. Panel a of Figure 1 shows the production profile of a typical agent in one of these primitive societies.

Figure 1 about here

B. High intelligence agents.

Agent intelligence as defined in this study has no impact on the individuals in this primitive society. Intellect reflects the ability of agents to remember beneficial partners and to learn trade protocols. In a society lacking trade, such abilities are useless.

2: A Pure Exchange Economy:

A. Low intelligence agents

Consider an economy without production but in which agents can trade. Agents are endowed with random amounts of g_1 and g_2 and their only question is to trade or not to trade. This is a more complex society as agents are aware of one another, they communicate, and negotiate prices and quantities for exchange. While such an abstract economy is primarily of theoretical interest, it is applicable to very short-run allocation problems. Suppose the production of g_1 and g_2 takes x hours but that the existing stocks of the goods can be exchanged immediately. If we restrict our observation to time y $(y<x)$, we would operate in a pure exchange economy.

This is a world of bilateral trade, agents simply swap goods for goods. At the time of an exchange, agents are constrained by their existing wealth, which consists of their current stock of goods 1 and 2. Agents trade as long as the incremental exchange increases U^i and while they can afford the exchange. In this barter economy the income constraint in each period t depends on their stock of goods and the existing price. It can be written as

$$(3) \qquad p_{i,j}(t)\cdot g_1^i(t) + g_2^i(t) = p_{i,j}(t)\cdot g_1^i(t-1) + g_2^i(t-1)$$

where $p_{i,j}(t)$ is the price of good g_1 between agents i and j in time period t.

An opportunity for mutually beneficial exchange exists if the marginal rates of substitution of two agents differ. With the utility function in (1), the mrs of agent i is

$$(4) \qquad mrs^i = \frac{U'(g_1^i)}{U'(g_2^i)} = \frac{g_2^i}{g_1^i}, \qquad i \in \{1,\dots,n\}$$

where $U'(\cdot)$ is the first derivative of U.

Starting with a population of such individuals decisions in this artificial economy are made sequentially. At the beginning of each round, an agent is selected to start the process. Call this agent the trade-initiating agent. He begins by calculating his marginal rate of substitution, as shown in (4), which reflects the amount of good 2 he would be willing to give up in exchange for another unit of good 1. He then randomly selects *m* other agents looking for beneficial trade opportunities.[3] Once a set of potential trading partners is selected, a price is negotiated with each agent in the set. Throughout these experiments the trading price between agent *i* and agent *j*, $p_{i,j}$, was set according to the following rule.[4]

$$(5) \quad p_{i,j} = \frac{g_2^i + g_2^j}{g_1^i + g_1^j} \qquad i, j \in \{1,\ldots,n\}$$

For simplicity, we assume all agents truthfully reveal their reservation prices for the goods, that is, each agent announces his or her mrs. After exchange prices have been established, each pair of potential traders negotiate a mutually acceptable quantity to exchange. This is accomplished through a series of hypothetical trades. During this hypothetical exchange agents trade one unit of good 1 for $p_{i,j}$ units of good 2, check their utility and if it has increased they swap another unit.[5] This continues as long as the exchange benefits both, but as soon as the marginal exchange reduces the utility of either agent trade negotiations stop. At this point no actual exchange has occurred, but the initiating agent remembers this potential deal. He then moves to the second of his potential trade partners and negotiates a deal with that individual. After bargaining with all *m* of his target traders, the initiating agent compares the utility gained from each of these possible trades and selects the best. This deal is consummated. So, if agent *j* was selected for trade, stocks of the goods owned by agent *i* and agent *j*, are adjusted to the

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[3] In these simulations $m = 10$.

[4] The geometric mean was also used as a pricing rule but it had little effect on our central conclusions.

negotiated outcomes. A second agent is then selected as the initiating agent and the procedure is repeated.

Selection of trade-initiating agents is made without replacement. So, once agent *i* becomes an initiating agent (the one who engages in search) he is not again selected as an initiating agent until all agents in the population have had the opportunity to search and trade. However, an agent can select any partner. Suppose agent *i* is selected as the first decision maker. He finds a partner and trades. Later in the same round a different agent, agent *j*, may select agent *i* as potential trade partner and if *i* offers the best deal, then *j* will trade with *i*. Thus, while agent *i* is selected as the initial decision maker only once per round, he may participate in trade numerous times if selected by other traders during the round. These rules insure that all agents will have the opportunity to trade at least one time in each round. Notice, any agent can either buy good 1 (trade g_2 for g_1) or sell good 1 (trade g_1 for g_2). Indeed, in successive rounds a particular agent may buy and later sell the same good.

The performance of this pure exchange economy was evaluated using the same ten populations used in the primitive "pure production" simulations. Naturally agents in the trade economy behave differently than in the production economy. Without production, there is no economic growth and so the most interesting macroeconomic result in the pure trade system is price convergence. Even though each agent bargained with only a fraction of the entire population in each round of trading, and even though they initiated trade only once in each round, the economy quickly reaches a steady state or equilibrium price. On average, it took only eight rounds for the economy to reach its equilibrium price vector.[6]

insert Fig. 2 about here

Price movements for all four economies studied here are shown in Figure 2. The lack of exchange in the pure production economy does not let prices converge as

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[5] There are transactions costs set equal 5% of the value of the exchange. This fee can be thought of as representing the negotiation, shipping, and billing aspects of trade. In this experiment these costs remain constant throughout the simulation.

[6] Prices are not identical, but close enough that the benefits of additional trade did not outweigh the costs.

shown in Panel a.[7] Panel b, in contrast, shows how rapidly the pure trade economy collapses on a universal price. Feldman (1973) studied the characteristics of welfare-improving bilateral trade and showed that as long as all agents possess some non-zero amount of one of the commodities (all agents have some g_1 or all agents have some g_2) then the pairwise optimal allocation is also a Pareto optimal allocation. In the pure trade economy, all agents are initially endowed with a positive amount of both goods, thus resulting allocations are Pareto optimal.

At the micro level, agents simply trade until there are no additional benefits to exchange. Individual traders rarely deal with the same agent more than once because previous trades tend to wipe out the advantage of dealing with that particular individual at a later date.

B. High intelligence agents

While the presence of intelligence has the potential of affecting these individual decisions because these agents do trade, in practice the impact of intelligence is virtually nonexistent. The benefits of additional trade between agents who have previously traded tend to be small because most of those benefits were reaped in their previous exchange. Thus, decisions are not significantly affected by intelligence.

3. Produce or Trade

A. low intelligence agents

The extreme models of pure production and pure trade primarily serve as introductions to the integrated system explored in the remainder of the paper. Suppose agents can produce or trade although their actions are restricted such that they can choose only one activity per round. This system has opportunity costs. If an agent produces good 1, he cannot produce good 2 or initiate trade with another agent until the next round of decision making. These opportunity costs suggest that production and trade take time and energy so choice must be made. Once again, an agent can be selected by other

[7] Although the pure production economy does not have prices (there is no exchange) we can still calculate a mrs for each agent, which is analogous to the price vector in the other systems.

agents as a trade partner and thus may trade more than one time during a round, but each agent can only initiate one activity, to produce or to trade, each round of play

Agents follow a decision process similar to the above model. Each round an agent is selected as the first "initiating agent". He randomly draws *m* other agents as potential trade partners, negotiates with each and ranks those opportunities based on how they affect his utility. He then explores the impact of production on his utility and from all of those choices he selects the best activity. Then a second initiating agent is chosen and the process repeats. A round continues until everyone has had the opportunity to initiate trade one time.

This "produce or trade " world has elements of both the pure production and pure exchange economy. And, as intuition would suggest, the performance of this economy often lies between those extreme cases. For example, prices converge more readily than in the pure production model, but they do not reach a single uniform price as in the pure trade model. Because agents often produce, the stock of each good frequently changes which triggers additional price adjustment. Panel c of Figure 2 shows this dynamic price movement. Although prices continue to change, their adjustment clearly falls within a well-defined range. In addition, with a choice between trade or production many agents do both. In the 10 simulations investigated here, 60% of the agents choose to trade in some rounds and produce in others. On average about 7.5% of all decisions are to trade.

However, some of this economy's macroeconomic attributes differ from the pure exchange and pure trade models. Economic growth is such an example. Even though there is a 7.5% reduction in the amount of time and effort going into production in this economy compared to the pure production economy, total output increases by an average of 18%. So, a 7.5% reduction in effort leads to a 18% increase in output. Clearly, there is some efficiency arising in this model that did not appear before.

Inspection of the dynamic decisions of individual agents shows how these efficiencies are achieved. Trade allows agents to specialize and focus on the activity that yields the highest return. Although the total amount of effort directed at production declines, it is concentrated in the areas of the agents' proficiency, thus, aggregate production rises.

This specialization occurs on a couple of levels; specialization in production versus trade and specialization in the type of production. If we collect each agent's decisions to produce or trade over the length of the experiment, we can rank each agent based on his or her frequency of production or trade. These agents would lie on a continuum ranging from "pure producers" to "pure traders". Table 2 takes such a ranking and places the agents into four groups: pure producers (agents who produce more than 99% of the time), heavy producers (agents who produce more than half the time but less than 99%), heavy traders (agents who trade more than half the time) and pure traders (agents trade more than 99% of the time). The bottom row in Table 2 shows how the population falls into each category. The majority of these agents lie in between the extremes, deciding to produce in some rounds and trade in others. And, most of those hybrid agents choose to spend more time producing than initiating trade. The modal decision is to produce and about 40% of the agents in these simulations choose production in virtually every round. However, the majority of the population chooses to trade more than once, but less than half the time.[8] The few remaining agents trade frequently. About 3% of these agents choose to trade more often than produce and about 0.4% evolve into pure traders.

insert Table 2 about here

Agents do not only specialize in production or in trade, some specialize in the type of good they produce. Table 2 also shows how each type of agent selects between specializing in the production of one good versus switching their production, sometimes producing one sometimes producing the other. The first column of Table 2, for example, shows that 40% of the population become pure producers. Of these producers, 21% specialize in the production of a single good. These are highly specialized agents, they specialize in production (versus trade) *and* exclusively produce one good. All of these highly specialized agents engage in "passive trade", that is, while they never initiate trade themselves, (because they always choose to produce) other agents select them as trading

[8] Remember, the phrase, "choose to trade" means this trader initiates trade. Agents trade at other times, called passive trades, when other agents select them as a trading partner and a deal is made.

partners. This passive trade is crucial for these producers, as it is their only means of obtaining the second good in their utility function. The remaining pure producers alternate between the production of one good and the other, usually following a one-period cycle. If these agents trade, they also do so as passive traders. But many of these agents are not even passive traders, that is, they engage in no trade whatsoever. Even though they may be selected as potential traders when other agents are randomly selecting targets, they never offer a price that elicits trade. They remain self-sufficient entities and do not interact with other agents.

The remaining columns in Table 2 disaggregate the decisions to specialize in the production of one good versus producing both goods by the type of agent. The majority of the agents fall into the "heavy producers" category (column 2), defined as individuals who occasionally trade (most trade less than 10% of the time), but spend more than half of their time producing. Sixty percent of these heavy producers also tend to specialize in the production of a single good. The typical pattern for one of these agents is to produce a particular good for several rounds, to initiate trade for one round (acquiring the other good), and then to return to the production of the other good. A visual image of the production/trade pattern of one of these agents appears in panel b of Figure 1. Notice how this agent's activity differs from the same agent in a pure production world (panel a).

Moving to the "mostly traders" category (agents who occasionally produce but decide to trade more than half of the time), we see that most of these agents, almost 90%, specialize in their production. The last category, "pure traders" do not produce at all; they trade.

In summation, when agents are given a choice to trade or to produce, many use this flexibility to specialize. In these simulations 45% of the population spends all of their production energy exclusively producing a single good. This is completely different than the pure production economy. With trade suppressed agents could not specialize and they spent close to half of their time on the production of each. The specialization brought forth by trade leads to efficiency as well. Even though fewer people are producing in the trade economy, output increases by 18%.

Closer inspection reveals the logic of the choices made by these agents. In these experiments production generally offers a greater return than trade because trade necessitates sacrifice, giving up one good to get the other, while production adds to your stock of goods and nothing is surrendered. Consequently, it is not surprising to find that 93% of all decisions are to produce. Second, since all agents have a symmetric Cobb-Douglas utility function, balanced consumption leads to greater utility, *ceteris paribus*. Thus, while agents want to accumulate more goods, they also want to even out their stocks of each. In the primitive pure production model, agents optimized these twin objectives by switching their production from g_1 to g_2 and back. In stark contrast, agents in the pure-trade economy could only raise their utility by moving ever closer to a 50/50 division of the two goods. But in the current environment, in which either trade or production is an option, an agent proficient in the production of g_1 can produce g_1 repeatedly and trade for g_2. Thus, while most agents spend less total time producing, they are able to spend that time at their proficiency. This gives rise to the most common type of trader in the economy, the heavy producer who occasionally trades.

Agents who are proficient in the production of one good but poor at producing the other tend to evolve into specialists who produce only their proficient good. Furthermore, one who specializes in a particular good is an attractive trade partner for others in the economy, for example if an agent produces only g_1, he tends to have a ready supply of g_1 and a demand for g_2. Thus, when these specialized producers are selected as potential trade partners through the random selection process of other agents, they frequently offer the most attractive deal. Consequently many agents who produce but a single good acquire their second good as passive traders. They need never initiate trade.

Agents who are highly proficient at the production of both goods tend to become self-sufficient individuals who never trade. They specialize in the sense of being pure producers, but they do not specialize in the type of production undertaken. Being highly proficient at both activities, self-production is almost always more beneficial than trade and they tend to switch their production back and forth from one good to the other. Typically their production is balanced with half of their time spent producing each good. These agents do not initiate trade, nor do they engage in passive trade. In these simulations about 20% of the population evolves into these self-sufficient individuals.

Towards the other extreme we find the merchants, agents who trade most, if not all of the time. In these simulations about 3% of the population is made of these merchants who never produce or rarely produce either good. These merchants are, in many ways, the most interesting group. They are born being ineffective at producing either good and when production leads to little gain, these agents find that they can accumulate greater wealth by buying one of the goods in one period and selling it in the next. In these simulations living solely by trade is a harsh existence in that these agents tend to accumulate less wealth than all the other types of agents. Still, trade significantly improves their plight because they are able to accumulate two to three times as much wealth in societies that allow trade than in societies that do not.

b. High intelligence agents

The final set of simulations maintains the same global environment in that agents can produce or trade, but it adds some intelligence to those decision-makers. Intelligence increases the agents' memory and learning, although the amount of retained information is limited. Specifically, agents remember the identity of agents offering the best deal on g_1 and g_2 from the previous two rounds and those agents are automatically included in the initiating agent's sample of potential traders for the current round. Recall that in the low intelligence simulations agents randomly selected *m* individuals in every round to be their potential trade partners. In this experiment agents automatically include the traders who have made them the best offers in the previous two rounds. Thus, as many as four agents are automatically included in negotiations and the rest of the *m* agents making up the potential traders are selected randomly.[9]

The second aspect of intelligence is that agents learn trade protocol with experience. Transaction costs accompany trade. In the previous simulations this cost was constant at 0.05 of a unit of g_1. In other words, if an agent swaped one unit of g_1 for one unit of g_2, he actually gave up 1.05 units of g_1 to get the single unit of g_2. High intelligence agents have the ability to learn and so these costs decline as they gain experience trading with specific partners. Thus, transactions costs, *tc*, become

[9] The number of previous agents included in this round of negotiation lies between 2 and 4 as one agent may have the best offer to buy or sell good 1 in the both of the previous two rounds.

$$(6) \quad tc = \frac{1}{10(1+t_i)}$$

where t_i equals the number of times these agents have previously traded

Using (6) transactions costs are initially equal to 0.1. With subsequent exchanges between the same two agents, however, these costs decline. Note that

$\frac{dtc}{dt} < 0; \quad \frac{dtc^2}{d^2t} > 0$ so transactions cost decline with trade, but the rate of decent slows with additional trades.

Once again the same ten populations of agents were turned loose in this environment and the overall demographic results are reported in Table 3. Adding intelligence has a small impact on this economic profile. Comparing Table 2 and Table 3 we see a spreading effect in the sense that more agents elect to not trade at all and the amount of trading undertaken by the most active traders tends to increase. Still agents can be aligned on a continuum ranging from pure producers to pure traders and the hybrid, infrequent traders still make up the lion's share of the agents. Furthermore, the same agents tend to evolve into the same type of players. Agents who were pure producers or merchants in the low intelligence simulations become pure producers and merchants in the high intelligence simulations. The most common type of agent is the individual who trades on occasion and tends to specialize in the production of one good the rest of the time. The proportion of the population that specializes in the production of a single good changes little with intelligence. Furthermore, returning to Figure 2, the dynamic price adjustment is very similar in the high and low intelligence simulations (compare panels c and d in Figure 2).

There is, however, a remarkable change in the *way* these agents fill their familiar roles. When agents are given some intelligence, they display a clear tendency to establish long-term exchange relationships with other agents. They revisit the same trader partners frequently and tend to execute a larger number of trades with a smaller number of people.

Emerging Order

Although the macroeconomic measures of the high and low intelligence simulations are similar, there is a remarkable degree of microeconomic structure that emerges in the high intelligence case. The extreme examples are the merchant traders, those hearty few who survive by buying cheap in one period and selling dear in another. When these agents locate another agent who is willing to part with a particular good inexpensively, and when they find a different individual willing to pay dearly for that good, they make their living by shuttling goods between those individuals. For example, in one of our experimental populations agent #18 is a heavy trader. In the low intelligence simulation he trades in 77 rounds. He also spreads his business around buying g_1 from 23 different people and selling g_1 to 24 additional people. In those 77 rounds of trading he deals with 47 different individuals. When this same agent is given a bit of memory and the capability to learn, he changes his behavior. He still evolves into a merchant and becomes even more active in trade, trading in 99 rounds, a 28% increase in trade. However, he buys from only nine agents and sells to nine others. On net, he trades many more times but with less than half as many people. In fact, four people account for almost half of his trades.

Similarly, his partners are also concentrating their business. For example, in the low intelligence simulation, agent #15 bought g_1 (as a passive trader, not initiating trade) 22 times from 16 different people, agent #18 being one of those suppliers. In the high intelligence environment, agent #15 is again a passive buyer, who now buys more often (35 times instead of 22) but he deals with only nine people.

Agents who trade less often also concentrate their deals onto a smaller number of partners, but the change is less pronounced. For example, in this same experimental population agent #86 is one of the infrequent traders. In the low intelligence simulation, he trades ten times with seven different people. With memory and learning, he trades eleven times but with only four other agents. Finally, those highly specialized agents who never initiate trade and exclusively produce a single good also narrow their customer base when memory and learning are involved. For example agent #12 never initiates trade, but passively agrees to buy g_1 thirteen times in the low intelligence simulation spreading his purchases among twelve people. In the high intelligence simulation he buys more frequently (21 times) but from fewer people (eleven different sellers). Since agent #12 only trades as a passive partner, he is not making this determination. It is the other traders who are initiating the trade who remember #12 and keep returning.

These examples suggest that with intelligence at least some agents tend to narrow their trading activity on to a particular set of trading partners. But antidotes cannot indicate the breadth or extent of such specialization. Consequently, we construct an index based on the Herfindahl index of concentration that provides a more accurate measure of the extent of this concentration. The Herfindahl index, *H*, was initially constructed to measure industrial concentration but it can be adapted to reflect the information we seek. Basing its calculation on the number of times that a particular trader trades with the same partners, this index is computed as

$$(7) \quad H^{i} = \sum_{j=1}^{k} (100 a_{j})^{2}$$

where a_j is the percentage of all trades made by agent *i* with agent *j* and where agent *j* is one of *k* agents with whom *i* trades.

The maximum value of *H* is 10,000 which indicates complete concentration (monopoly). As the number of traders grows and trade is spread more evenly the index falls. These concentration rates were calculated for a representative sample of each type of trader in the ten populations. The average indices are reported in Table 4.

Table 4 about here

The concentration measures in Table 4 show a consistent pattern. As agents gain intelligence they tend to revisit the same trading partners. This tendency to converge on a few traders is most pronounced for agents who trade frequently. Reading down the columns in Table 4, the concentration index increases three-fold for the heavy traders and pure trading individuals. The same compression occurs with the infrequent traders who spend most of their time producing, although the impact is not as large. Specifically the concentration index doubles when the heavy producing agents gain intelligence.[10]

In general the presence of memory and learning leads to long term exchange relationships as agents take advantage of the information they have accumulated from previous experience. Traders organize themselves and deal more frequently with a smaller group of individuals. This result begs a further question. Once these intelligent traders have built a relationship with a couple of agents who are proficient producers and who therefore offer attractive deals, why do they switch partners at all? Because our decision-makers are artificially constructed, we can explore the dynamic decisions of each agent and see why they occasionally switch partners.

Consider the quintessential merchant, an agent who never produces but survives by buying g_1 in one period and selling it in the next. Every round this trader remembers the agents offering him the best deals in the last two periods, but he also shops around a bit. Specifically he randomly samples of m-p people (p being the number of past, remembered agents) and compares offers among that group. After several rounds, this trader has seen a large portion of the population. Suppose he has located the single agent who is the best source (the most proficient producer) of g_1 in the economy. This merchant returns to his proficient producer every round (he remembers the best deal), but buys from him every other round (half of the time he is selling the g_1 he has acquired). Now, suppose there is another agent who is an inferior producer of g_1, but for whom g_1 production is the best alternative. This second producer may not find buyers for his product for several rounds and thus he begins to accumulate g_1.   This accumulation reduces his asking price until a round arises in which he offers a better price than the more proficient agent. Our merchant, never passing on a better deal, eschews his long-term partner and buys from the second agent.

A single buy from a different supplier, however, does not disrupt the long-term relationship with the original supplier because memory lasts for two rounds, i.e., in the subsequent round the merchant will revisit both the primary and secondary producer of g_1. Since the secondary producer has sold off his accumulated stock of g_1 his price is no

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[10] It is not appropriate to compare these index numbers across columns because the number of firms in each group differs significantly. Thus, the heavy producers' index numbers are inflated relative to the

longer competitive and the merchant will resume his relationship with his primary producer.

With a little different timing, however, the same string of events can lead to a permanent change of partners. Recall that the merchant buys g_1 every other round (he is selling the rest of the time). Suppose our secondary producer (who has been accumulating g_1) offers his superior deal during the off period, when the merchant is selling g_1, not buying. Now his offer will be rebuffed, but remembered. The next period, the secondary producer is still likely to be offering better price because he has not yet sold his accumulated inventory. If so, the secondary producer makes the sale. Again this may be the only sale the secondary producer makes for awhile because he is not as proficient in the production of g_1. More importantly, however, this secondary producer has now offered the best price for two contiguous rounds, thus, the merchant will have forgotten the identity of his long-term supplier. He last contact with that agent was three periods ago. In subsequent rounds the merchant moves from one supplier to another until his random shopping locates another highly proficient provider of g_1 (or relocates his original supplier).

This string of events leads to the results we observe in these simulations. Agents build long-term relationships with specific agents but occasionally they break off these contacts. Clearly, longer memory would lend more stability to these exchange relationships. However, agents would still switch partners when two of these disruptive events occurred in tandem, or within one period of each other.

The issue here isn't that more memory stabilizes a long-term relationship. The important issue is that it takes very little intelligence to generate long-lived relations. So, while the relationships emerging in these simulations are fragile in the sense that they can easily be disrupted, they are actually quite persistent. It takes but a single agent with a one-time attractive offer to disrupt an existing partnership but we still observe significant concentration for all types of traders. It seems that it doesn't take much, just a bit of memory and little learning, to have organizational structures emerge spontaneously and to persist over time.

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heavy traders'. Down a column, however the number of firms is more consistent.

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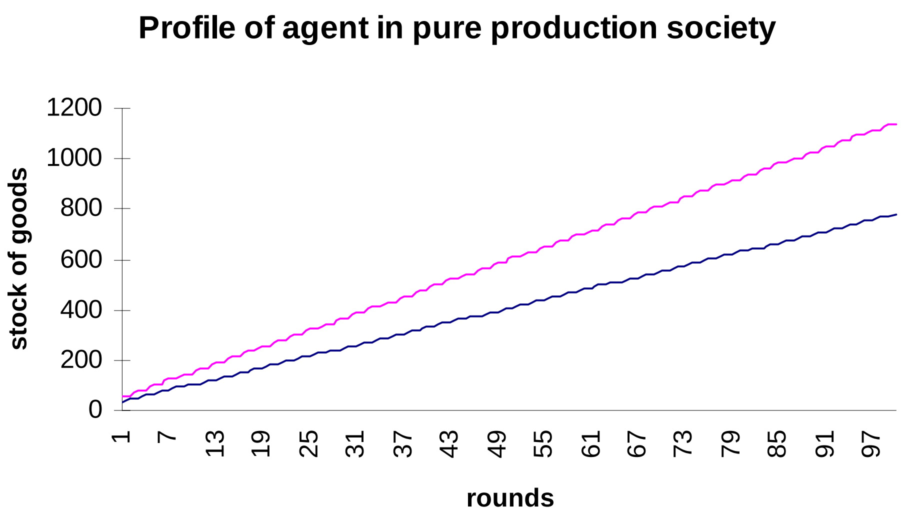
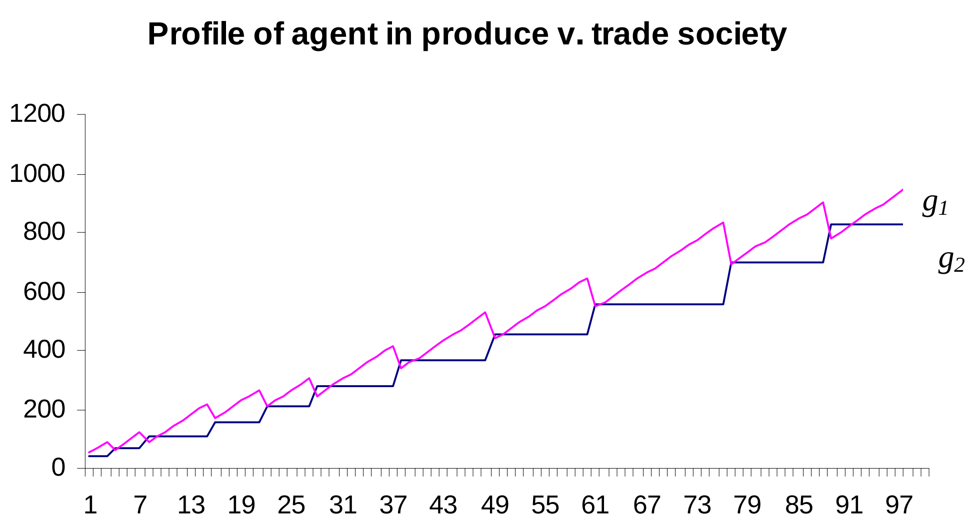
Figure 1

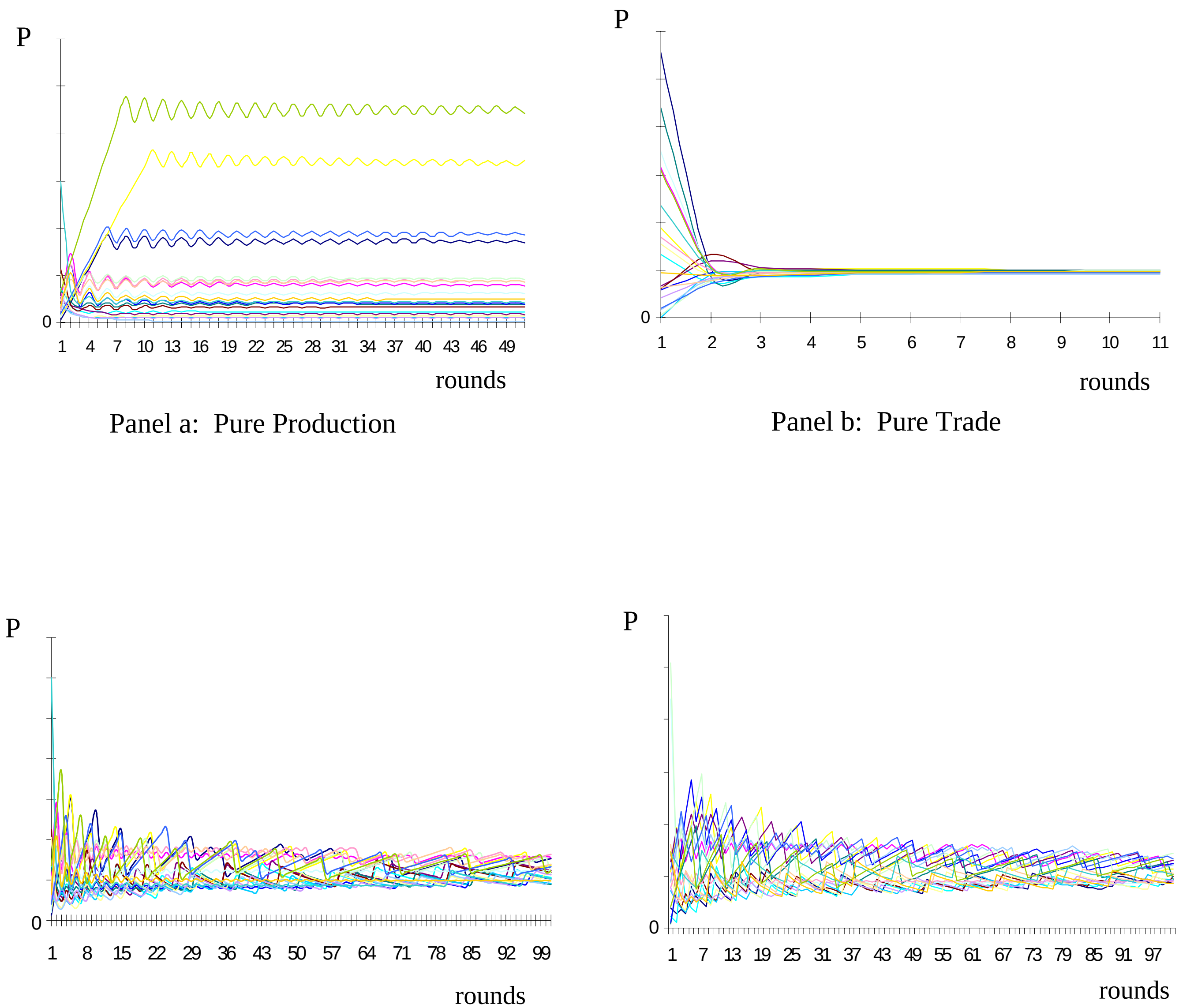


Panel a:
The typical agent in the pure production society simply switches his production from good 1 to good 2 and back again. The profile shows his accumulation as he adopts this strategy.



Panel b:
An agent in the produce or trade world who is a heavy producer, produces several rounds (increasing his stock of g_1 as g_2 remains unchanged) and then in one round trades a large amount of g_1 for g_2.

Figure 2
Price Dynamics in four artificial economies



Panel a: Pure Production

Panel b: Pure Trade

Panel c: Production v. Trade
Low intelligence agents

Panel c: Production v. Trade
High intelligence agents

Table 1
States of the World

	pure production	pure exchange	production or trade
low intelligence	1a	2a	3a
high intelligence	1b	2b	3b

Table 2
Two-way Specialization in Trade v. Production
Low Intelligence Agents

	Pure Producers	Heavy Producers	Heavy Traders	Pure Traders
specialize: (produce one good)	8.5% (21.0%)	33.5% (59.6%)	2.6% (89.7%)	0% (0%)
do not specialize: (produce two goods)	32% (79.0%)	22.7% (40.4%)	0.3% (10.3%)	0% (0%)
Totals	40.5%	56.2%	2.9%	0.4%

The top number displays the percentage of the entire population falling into that cell. The lower number displays the percentage of agents in that category (column) falling into that cell.

Table 3

Two-way Specialization in Trade v. Production
High Intelligence Agents

	Pure Producers	Heavy Producers	Heavy Traders	Pure Traders
specialize: (produce one good)	11.4% (23.0%)	29.6% (64.2%)	3.1% (91.2%)	0% (0%)
do not specialize: (produce two goods)	38.2% (77.0%)	16.5% (35.8%)	0.3% (8.8%)	0% (0%)
Totals	49%	46.1%	3.4%	.9%

The top number displays the percentage of the entire population falling into that cell. The lower number displays the percentage of agents in that category (column) falling into that cell.

Table 4

Measures of Concentration (Herfindahl type)
High Intelligence v. Low intelligence agents

	Heavy Producers	Heavy Traders	Pure Traders
Low Intelligence agents	2007.1	619.6	561.6
High Intelligence agents	4206.8	1891.5	1675.6