Integrating Segregated Markets

Dan Ladley\textsuperscript{1} Seth Bullock\textsuperscript{2}

\textsuperscript{1}Centre for Advanced Studies in Finance
Leeds University Business School
University of Leeds, UK
danl@comp.leeds.ac.uk
+44 (0)113 3436804

\textsuperscript{2}Science and Engineering of Natural Systems
School of Electronics and Computer Science
University of Southampton, UK
sgb@ecs.soton.ac.uk
+44 (0)23 8059 5776

Abstract: In many cases real markets are segregated to some extent by constraints on who is readily able to trade and communicate with whom. This kind of segmentation is modelled within a market constrained by an underlying network topology. The impact of segregation on market convergence is quantified, and the extent to which it is redressed by a broadcast mechanism intended to mimic the presence of information sources that are widely consulted, but imperfect, and slow to react to market change is explored.

Keywords: market, network, agent based economics, entropy.

1. Introduction

Many results in economic theory are based on the assumption that markets are centralized structures within which all traders (whether customers, retailers, or financial traders) are able to trade and interact freely with each other. As a consequence, each has access to identical information and trading opportunities. With the possible exception of some computerized financial exchanges, the vast majority of markets are not like this. Factors such as the spatial locations of traders, their personal trading histories, and reputations, amongst others, may all play important roles in governing the nature of trade. Given these influences, in some cases it is more appropriate to consider markets as being groups of individuals interacting across a social network. There have been a small number of studies that have started to take this viewpoint \cite{1}\cite{12}. However, understanding the effects of limited connectivity within a market on its behavior remains an open question.

A purely social network-based view of markets remains an oversimplification. Although it may be reasonable to represent trade as a process mediated by a network, in that trade may only take place between those individuals in direct contact with each other, making the same assumptions about information transfer within a market is not valid. It is true that much information will be transferred via the same social network that underpins trade. However, it is also the case that in most markets there are additional global information transfer processes. These processes often transmit less information at lower fidelity and with less immediacy. However, the information is often more widely disseminated. For instance, consider the effect of product advertisements within retail markets. Although direct interaction with others in the market may provide information that is more detailed or reliable, advertisements will tend to achieve greater penetration, spreading information further and more rapidly.

Here the way in which constraints imposed on trading interactions impact on the ability of a market to converge is explored. By implementing a simple market across a variety of social network topologies and using entropy measures to track convergence, it is possible to quantify the impact of market segregation. Subsequently a broadcast mechanism intended to mimic the presence of information sources that are widely consulted, but imperfect, and slow to react to market change is introduced. The tendency for this mechanism to partially integrate segregated markets is demonstrated, and its significance discussed.

2. Microeconomics and Markets

Broadly speaking economics consists of two fields, microeconomics and macroeconomics. Macroeconomics is the study of economies as a whole and the effects on them of various forms of control. This paper is solely concerned with microeconomics, the study of markets, and in particular the study of the structure of markets and of the processes that occur on them \cite{7}.

A market is an institution within which traders come together to trade goods. When a trader wishes to advertise a price they \textquoteleft \textquoteleft make a shout\textquoteright. If a trader wishes to buy a quantity of goods the shout is called a \textit{bid} and specifies the price that the trader is willing to pay for the quantity of goods. If the trader wishes to sell a quantity of goods the shout if referred to as
an offer and specifies the price that the trader is willing to accept for that quantity of goods.

In a market, the exact way in which buyers and sellers are allowed to communicate and trade is dictated by a market mechanism. Many different market mechanisms are employed. Some of the most common are the English auction, the Dutch auction and the continuous double auction. These market mechanisms differ in terms of who may make shouts and when they may make them. In an English auction only buyers may shout and each bid must be greater than the previous bid, the buyer with the highest bid taking the goods. Conversely, in a Dutch (flower) auction only sellers may shout, and each offer must be lower than the previous one. When a price is reached at which a buyer is willing to trade the auction ends and the buyer and seller trade at the agreed price. In a continuous double auction both buyers and sellers may shout bids and offers at any time. When a bid and offer cross (i.e., a buyer makes a bid which is greater than the lowest offer, or vice versa) a trade occurs. It has been demonstrated that different market mechanisms have different properties in terms of their efficiency, and whether buyers or sellers are favored [4].

A market's efficiency is typically measured in terms of its ability to find and maintain the equilibrium price. In a market the equilibrium price is the price at which demand for a good is equal to the supply of that good. The supply and demand of a good at a particular price may be determined from the utility placed on the good by traders in the market. This is sometimes expressed in terms of limit prices. A buyer's limit price is the maximum price that they are willing to pay for a unit of goods. For a seller, it is the minimum price that they are willing to accept for a unit of goods. A supply/demand graph may be formed by plotting the supply and demand of goods for all possible prices, the point at which these supply and demand curves cross being the equilibrium price. At the equilibrium price the maximum amount of profit is made by agents in the market. One of the key properties of markets is their ability to converge on the equilibrium price. The continuous double auction in particular is able to find this price very quickly [4][9].

This balance between integration and segregation may have important consequences for the behavior and performance of markets. There are many possible reasons for traders to be tightly coupled. For instance, in a food market geographical factors may be highly significant, with agents living in the same village forming a clique. In a financial market, traders working for the same investment company or those trading in a particular commodity may become highly integrated. Indeed, there are likely to be functional modules of this kind at many levels of abstraction.

In a completely integrated market, every agent is tightly coupled to every other agent. Everything that any agent knows is known by every other agent and is used by every other agent to guide their future decisions. This would have two potential consequences. First, if the agents are rational, as is assumed in most market models, the market will be completely efficient. Every agent knows the exact value of all commodities and the available supply and demand. Therefore, all trades occur at the equilibrium price and every agent capable of trading at that price will find someone to trade with (as supply matches demand at the equilibrium price). This means that there is no possibility to make profit in the market since it will only be possible to buy or sell a good at its true market value--there is no way to buy a good from one person and sell it to another at a profit.

If it is no longer assumed that all agents are completely rational, a fully integrated market may become highly unstable. Boundedly rational traders may be unable to immediately calculate the implications of the information that they receive from the rest of the market. As a result, any changes in the underlying supply and demand schedule have potential to destabilize in the market. Consider an event external to a fully integrated market that impacts on demand for the commodity being traded. Although this information is by definition equally available to all traders, it will lead to a variety of responses made at a variety of speeds. The nature of this sudden variability across the market will also be immediately available to every trader, since they are all tightly coupled to each other, and will also lead to changes in trading behavior, as traders seek to exploit transient opportunities. These new changes to trading behavior will also impact differentially across the market, and so on. In this case the completely integrated nature of the market encourages variable and potentially pathological behavior to cascade through the market, even though there may be no strategic reason for agents to behave differently to one another.

By contrast, a functionally segregated market would consist of small isolated groups of traders who are able to trade reasonably freely amongst themselves, but who have little ability to trade with other groups. The price of any particular commodity would then depend strongly on the local conditions within a particular group. For instance, if there were a drought in one functional area, it would lead to a substantial drop in supply of food forcing prices upwards. At
the same time, if there were good growing conditions in another functional area, increased supply would force food prices down rapidly. If these areas are functionally segregated, there is no way for goods to be traded between them. Therefore, in general this would lead to price imbalances and possible trades failing to be made.

An optimal market (and every real-world market) clearly exists somewhere between these two extremes. An ideal market would be sufficiently integrated to allow free trade between units and to prevent very large price differences. However, it would also maintain sufficient segregation, such that it is resilient to shocks. Most market simulations assume the markets are completely integrated, i.e., all traders are equally strongly connected to all other traders within the market. This, however, is unlikely to be the case in real markets as it would require an incredible amount of information gathering, transport and analysis. Here the behaviour of simple simulated markets implemented over networks that have the potential to segregate traders is explored together with the action of mechanisms that may combat this type of segregation.

4. Method

In recent years, agent-based simulations of markets have started to gain prominence [10]. These models allow the construction of "virtual markets" within which agents negotiate and trade goods. These markets are useful as they provide a new method of exploring hypotheses about markets. Computational market "experiments" have several advantages over traditional market experiments. Most importantly they are repeatable, allowing behavior under different parameter combinations to be characterized statistically. By contrast, real markets are composed of unique, unrepeatable events. It is not possible to rewind a real market in order to check a result or to test the same market under slightly perturbed conditions. In addition, it is possible to obtain information from computational markets that isn't normally available in real markets, for instance, private information from silent agents. The advantages of computational markets have been exploited for several purposes. Research has focused on the design of market mechanisms to encourage efficient trade, the design of trading agent algorithms that are able to make profit as well as the properties and responses of markets in particular situations [4][5][6]. However, a major disadvantage of computational markets is that they are only simulations. This means that computational "experiments" do not generate empirical data in the same sense that real experiments do. Rather these simulations could perhaps be better viewed as a kind of computational thought experiment, shedding light on theories of the way that markets behave.

Here a simple agent-based computational market that takes place on a network that constrains which individuals may trade with each other is developed. All experiments were run with a total of one hundred traders, half of which were consumers/buyers, while the other half were suppliers/sellers. Consumers/buyers were each assigned a limit price of 200 whilst suppliers/sellers were each assigned a limit price of 100, respectively. These limit prices prescribed the value that the buyers placed on one unit of the traded commodity and the cost incurred by sellers/suppliers in producing one unit of the commodity. As a consequence these prices were the maximum price that a buyer would be willing to pay in order to obtain one unit of the commodity and the minimum price that a seller would be willing to accept in exchange for one unit of the commodity. Market theory dictates that this particular supply and demand schedule will allow the equilibrium price to be anywhere within the range (100,200). Each agent is able to trade an unlimited number of times during the course of a simulation. These experiments were concerned with the degree to which a market converges, rather than the value that it converges to. It may be preferable to think of trade occurring over an extended period of time, suppliers producing more of the traded commodity and buyers re-entering the market regularly to acquire more of the commodity. This particular schedule allows the market to converge to one value, whereas a crossed schedule, for instance, would ensure that some agents have limit prices that prevent convergence.

In order to accommodate the market's network structure, a very simple take-it-or-leave-it shout based auction scheme implemented in discrete time was employed. This scheme was chosen primarily for its simplicity and transparency (though see [3] for inspiration and justification of this type of market implementation). It simply models sellers and buyers entering the market and shouting prices at which they wish to trade, other traders then have the option of taking them up on their shout. At each time step a trader is selected at random from the market and allowed to make a bid or an offer (depending on whether the trader is a buyer or seller) with value determined by the agent's trading algorithm (described below). The agent's shout is heard by every active network neighbor. Of those that are willing to trade at the price shouted, one is chosen at random and the trade executed. The simulation terminates after a specified number of such time steps.

The behavior of each trading agent was determined using the Zero Intelligence Plus (ZIP) trading algorithm [2]. This is a very simple mechanism that combines constrained random behavior with a learning algorithm that adapts the agents' behavior on the basis of information gleaned from trading activity in the market. Each ZIP trader has an adaptable profit margin, SmS, associated with its fixed limit price. For buyers, this profit margin is the amount by which they currently wish to undercut their limit price when they trade. For sellers, it is the amount by which they wish to exceed their limit price. From this profit margin it is possible to define the traders shout price, \( p \), as

\[
p = l(1 + m)
\]
where \( l \) is the traders limit price. This shout price is then the price that traders shout if chosen and is the worst price that a trader will accept to trade at. The ZIP algorithm adapts this profit margin throughout an agent's lifetime in order to maximize the possibility of making a profitable trade.

After each shout within the market all traders connected to the shouting trader (including the shouter themselves) adapt their profit margin in the following manner. In the trader is a buyer and they hear a shout at price \( q \) which is accepted then if \( p \geq q \) the trader should raise their profit margin, if the shout was an offer and \( p \leq q \) the trader should reduce their profit margin. If the last shout was a bid which wasn't accepted then if \( p \leq q \) the trader should lower their profit margin. These rules are defined analogously for sellers (For full details, see [2]).

When required to adjust their profit margin the traders do so using the Widrow-Huff learning rule with momentum [14]. This learning rule allows agents to rapidly converge on the optimal price, while the momentum term allows blips in the market to be ignored. For ZIP traders the learning rule is defined at time \( t \) as

\[
m(t+1) = (p(t) + F(t))/l - 1
\]

where \( F(t) \) which represents the effect of momentum and is defined as

\[
F(t+1) = yF(t) + (1-y)\delta(t)
\]

and where \( \delta(t) = \beta(\tau(t) - p(t)) \) and \( y \) is the momentum term and \( \tau(t) \) is the target or desired output price and is calculated as

\[
\tau(t) = R(0)q(t) + A(t)
\]

\( A(t) \) is a uniformly distributed random number in the range \([0.05,0.0] \) for price increases and \([-0.05,0.0] \) for price decreases. \( R(t) \) is drawn at random from a uniform distribution in the range \([1.0,0.05] \) for price increases and \([0.95,1.0] \) for price decreases. Together these parameters are responsible for small relative and absolute perturbations to the target price. Here, each ZIP agent was initialized with a random profit margin, \( p \), drawn from a uniform distribution \([0.05, 0.35] \), a random learning rate drawn from a uniform distribution \([0.1, 0.5] \), and a random momentum value drawn from a uniform distribution \([0.2, 0.8] \). The parameters used here are identical to those used by Cliff and Bruten [2].

As a measure of market convergence, entropy was calculated from the valuations of the traders within the market. At each time step, every active agent was polled for the price it would shout at the next time step given the opportunity. From this it was possible to form a probability distribution over the range of valid prices and from this it to calculate the entropy present in the system. Entropy is a good measure of price variability in potentially segregated markets, since it measures the price convergence, or lack there of, whilst not assuming a uni-modal price distribution.

5. Results

Figure 1 depicts market convergence in a fully connected network. Market entropy falls rapidly, but stabilizes at a value significantly above zero, indicating that traders do not completely agree on a valuation of the commodity being traded. This is due to residual variability in the behavior of the traders at equilibrium. Although, in the limit, the market should converge completely, ZIP traders tend to explore prices that slightly increase their profits. As a result of this behavior the valuations are somewhat spread.

Figure 1 also depicts market convergence in a ring network, where agents are only able to communicate and trade with the agents on either side. Although it is not believed that markets typically demonstrate this particular structure, it does contrast sharply with the standard, fully connected market topology described above. A ring topology ensures that some agents are a large number of steps away from potential trading partners. Figure 1 demonstrates that the constraints on information flow and trading activity imposed by the ring topology have interfered significantly with market convergence. As the path length between some pairs of agents is now relatively long, it is possible for different areas of the market to converge to different prices, leading to the increased level of entropy.

Finally, figure 1 shows the market convergence in a small world network, identical to a ring network with the exception that \( R \) edges are randomly rewired. The introduction of these random cross connections dramatically reduces the path length between some pairs of nodes [8]. As a consequence the market is more integrated and does not converge to such widely separated values. Note, in this experiment \( R \) is large with respect to standard small world networks of this kind [12]. This is because half of the cross connections will be between traders of the same type (e.g., two buyers) and thus will have less impact on market behavior.

Figure 2 depicts the relationship between a market's connectivity and its asymptotic entropy. The networks in question are random graphs where every pair of vertices is connected by an edge with fixed probability, \( p_e \). As \( p_e \) increases, initially market entropy falls rapidly as edges link increasingly large parts on the market together, significantly effecting its ability to converge. Around \( p_e = 0.075 \) this rapid decrease stalls, and subsequently there is only a very slow decreases in market entropy as increasing interconnection has relatively little effect on market convergence. It appears that once the market reaches a critical number of connections, considerably higher than the percolation threshold, additional connections have relatively little effect. For a random network of this size the percolation threshold is
Fig 1: Market entropy averaged over 1000 runs.

Fig 2: Depicting the relationship between market entropy and the connectivity of a market of 100 traders, ranging from a completely disconnected network on the left to a completely connected one on the right. Each data point represents a sample of 100 networks.
Fig 3: Depicting the impact of random rewiring events on the characteristic path length, clustering coefficient and asymptotic market entropy of markets initially constrained to take place on ring networks (n=2). Values are normalized relative to those calculated for an unperturbed ring network. Each data point represents a sample of 1000 networks.

Fig 4: Depicting the impact of random rewiring events on the characteristic path length, clustering coefficient and asymptotic market entropy of markets initially constrained to take place on ring networks (n=5). Values are normalized relative to those calculated for an unperturbed ring network. Each data point represents a sample of 1000 networks.
approximately 2/99, however, in this model information is transferred differently between traders of different types i.e. buyers and sellers, than it is between traders of the same type i.e. buyers and buyers. For this reason a more appropriate estimation of the percolation threshold may need to assume a worst case situation that only half of the connections carry useful information/allow trade resulting in a threshold nearer 4/99.

There is a small anomaly at very low levels of connectivity where the addition of extra edges actually increases market entropy. The reason for this is that when there are no edges, any shouts made by traders are not responded to---no trades are made. This results in profit margins being revised downwards until, eventually, minimum acceptable prices are Reached (though of course this happens very slowly). When a very small number of edges are added isolated small groups of traders are able to communicate and trade. As a consequence, there is a separation of behavior within the market and an increase in entropy. With the addition of further edges, however, there are sufficiently many connections within the market that large groups start to behave in an increasingly coordinated manner, with an attendant fall in market entropy.

Figure 3 and figure 4 depict the relationship between asymptotic market entropy and network structure (in the form of characteristic path length and clustering coefficient) for markets constrained to operate over ring networks that have been subjected to a number of random rewiring events. As the number of these events increases, initially market entropy drops. However, while characteristic path length continues to fall with increasing numbers of rewiring events, the market entropy quickly asymptotes at approximately 80% of the entropy present in the initial ring-network market. Note that the characteristic path length of an n=2 ring network eventually begins to increase as a large number of edges are rewired. This results from the network fragmenting into isolated components with sparse connectivity.

Figure 5 depicts market convergence in the same classes of network (fully-connected, ring, and small world) save that they have each been augmented by the addition of a broadcast agent: a randomly chosen ZIP agent, initialized as before, save that its initial profit margin is mid-way between the limit prices for buyers and sellers (here, 150), and it is connected to every other trading agent in the market. This broadcast agent does not trade in the market, but, as before, does adapt its profit margin on the basis of the market behavior that it observes. Every k timesteps, the agent makes a shout at its current valuation. Half the time this will be a bid, and half the time it will be an offer. Although no trade can actually take place, all agents adapt to this shout as if one has. The broadcast agent's profit margin is then reset, and it is randomly assigned to adapt like a buyer or seller for the next k timesteps (k=20 for all results reported here).

This mechanism was inspired by the role of global, low-fidelity information sources such as the financial press, which give an averaged picture of the behavior of markets in the recent past to all traders who choose to make use of it. This type of process could be viewed as a form of market modulation in that it operates at a slower timescale than the market (once a day as opposed to instant trades), has a wide spread effect (it may be read by everyone), and has an averaging effect (reporting the day's statistics, say, as opposed to data concerning a particular trade). Other market modulatory processes include certain government behaviors (e.g., interest rate rises), the behavior of other markets, and the behavior of companies, all of which have wide ranging effects, which can radically alter agent behavior.

The addition of this broadcast mechanism has little effect on the fully connected market, since every agent already hears all bids and offers from every other agent. In contrast, and predictably, the segregated markets evidence significantly reduced entropy, indicating that the broadcast mechanism has encouraged increased market convergence, despite explicitly not increasing the number of agents who may trade with one another.

The broadcast information also introduces a regular saw-toothed pattern in the entropy traces. Between broadcasts, valuations in the segregated markets drift apart, increasing market entropy. The broadcast process, however, counters this by regularly providing all agents with the same information, which encourages integration and so reduces entropy. Interestingly, when the broadcast process is added to the n=2 ring, the market achieves a lower entropy value than even the more well-connected rings. This is because agents within the n=2 ring receive proportionally more information from the broadcaster, who accounts for one third of their input connections and 5/7 of the shouts that they hear. This ensures that, although they receive less information than agents in other topologies, they pay more attention to the same broadcaster, and as a result tend to more readily agree on a market price.

### 6. Discussion

The results reported in this paper demonstrate that the structure of the market has important ramifications for the flow of information within it. By segregating the market, through the use of a ring topology, it has been shown that market convergence can be impeded by market structure. By randomly reconnecting a small number of edges to produce a small world, it was possible to increase the convergence of the market somewhat---such cross connections provided information links between areas that were otherwise isolated from each other.

Surprisingly, however, the introduction of cross links via rewiring only had a relatively small effect on the entropy within the market. Results from networks theory regarding path length in small world networks and from many practical
applications suggest that the addition of cross connections would have a marked effect on average path length (as observed). This shortening of the average path effectively means that all members of the market are on average closer together and so it is not unreasonable to expect that even with only a few cross connections the market would be much more converged. In this model, however, this is not the case. As average path length decreases there is a decrease in entropy, however, this decrease quickly reaches an asymptote significantly above the levels of entropy and therefore convergence achieved in completely connected markets. It appears that although cross connections provide a mechanism for the transfer of information rapidly across the market they do not provide sufficient quantities to ensure convergence.

The results obtained from the class of random graphs support this point. It can be seen that as the number of connections at the ends of the small world links will hear a small amount of information from a long way away and a large amount from close to them due to their greater connectivity to their local area. As a consequence even though they do take into account the information source on the cross link, the signal from it will be aggregated together with the much larger quantities of information from the near neighbors. When this trader then passes information to its neighbors they will only be getting a small fraction of the information from far away increases the market entropy decreases i.e. the market becomes more converged. In particular there appears to be a critical density of connections (about 7.5% of those possible) that once achieved results in this convergence. If the number of connections is increased beyond this point then the behavior of the market will become more tightly coupled though only slightly. At this point there are sufficient connections for information to pass between traders at a sufficient quantity to maintain cohesion. If there are less than this critical level of connections the market entropy is significantly higher. Different parts of the market may converge to different values as there may be insufficient information transmission across the market.

This lack of strong coupling may be the reason why the small world links fail to result in significantly better convergence even though path length is significantly reduced. The trader as it will have been heavily diluted. In small world networks average path length is relatively short, however, due to the way that information is aggregated together by traders this appears not be sufficient to ensure a signal travels more than one or two connections. It is only if there are multiple connections allowing a greater strength of signal to propagate that information can travel across the network and effect convergence. Random graphs with a degree of connectivity greater than the critical point provide these connections

Fig 5: Broadcast-augmented market entropy averaged over 1000 runs.
enabling a greater degree of convergence, whereas by their nature small world networks do not. This argument is also supported by the critical point for convergence of random network markets being above the peculation threshold. If path length were the only important factor then it would be expected that markets would be highly converged/coupled with a number of edges dictated by the peculation threshold. The fact that this convergence only happens at a significantly higher point indicates a much greater degree of coupling is needed as described above.

The presence of a critical point suggests that in markets that are segmented and that have high degrees of price variance, if the degree of interconnection can be increased (possible even slightly) then this variance may be reduced dramatically. Methods for doing this are, however, not always intuitively obvious.

Rings and fully connected markets are extreme topologies. In one case a system that is maximally integrated, and in the other, a system that is minimally integrated without completely fragmenting. There exist a whole range of intervening potential market architectures that need to be investigated in order to better understand the effect of market topology on market performance and the ability of traders to function.

There are many possible ways in which the performance of more complex market structures could be examined. One possibility is to borrow tools from neuroscience with which to measure functional integration. Measures such as mutual information and information integration would be of particular interest as they allow the identification of functional units within the system, for instance those that have a particularly large impact on the price-setting process. These measures are not necessarily limited to simulated markets, but could also be used to characterize the functional units in real markets using market history data.

These results clearly show that the addition of the broadcast process encourages the market to become more tightly converged. A converged market is efficient, and tends to limit the potential for traders to be exploited. Interestingly, the broadcast information did not allow the market to achieve complete convergence, and also introduced characteristic saw-toothed microstructure in the market behavior. Its impact was also most strongly felt in the most highly segregated market explored here, allowing it to outperform more integrated markets.

It is unclear, however, how an equivalent to the broadcast process could be implemented and managed in a non-toy computational market. There are two main issues. First, the design of the system. It is not claimed that the mechanism implemented here is particularly representative of systems found in real markets, or that it is optimal in any sense. In order to represent the process within the framework of a standard ZIP market, a single agent, adapted to behave more like a commentator than a trader was employed. Conversely, the rest of the market treats the broadcast information as if it were just another trade. By contrast, the modulatory processes involved in neural systems are wholly unlike the neural network activity that they are implicated in regulating.

Second, how should such a system be supported? In this paper the market modulatory process is provided for free. However, real market equivalents are not. Very low fidelity information is often available for very little cost e.g. Financial Times. However more fidelity information are available for non-trivial prices. How then should agents pay for this information? How should the quality of information be related to the price? How should an agent choose between multiple possible sources of extra information? There are many issues that need to be resolved before these processes and their effects on market behavior can be understood.

7. Conclusion

It seems likely that traders in large markets will not be able to attend to, or interact with, every other trader in the market simultaneously. However, it also seems reasonable that they will not simply ignore the portion of the market from which they are segregated. Instead they will attempt to gain some type of overview of it. This paper is a first attempt at combining these elements in order to gain a better understanding of market processes as a whole and the feedback between the market and its modulatory processes.

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Author Bios

Dan Ladley obtained his undergraduate degree in Computer Science from the School of Computing at The University of Leeds. He is currently studying for a PhD in Computational Finance jointly between Leeds University Business School and The School of Computing under the supervision of Prof. Klaus Reiner Schenk-Hoppé.

Seth Bullock After gaining a BA in psychology and computer models (cognitive science) and a DPhil (PhD) in artificial intelligence from the School of Cognitive and Computing Sciences (COGS) at the University of Sussex, Seth Bullock spent two years in Berlin at the Max Planck Institute for Human Development simulating the evolution of adaptive decision-making behaviour in people and other animals. In 1999 he took up a five-year University Research Fellowship at the University of Leeds, founding the School of Computing's Biosystems group. In October 2005 he joined the University of Southampton's School of Electronics and Computer Science as Senior Lecturer in, and founding member of, the newly formed Science and Engineering of Natural Systems research group. Seth Bullock's principal research interest is evolutionary simulation modelling: the application of individual-based evolutionary modelling techniques developed within artificial intelligence and complexity science to problems within evolutionary biology and other disciplines, e.g., linguistics, economics, psychology, geography, anthropology, computer science, etc..