Effect of market type in continuous environments: The need for intermediaries

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ABSTRACT

Much research on automated market design has focused on auction mechanisms that require both a centralised auctioneer and strategic behaviour of individuals to achieve competitive outcomes. This new research investigates the performance of several market types in terms of global efficiency and individual trader outcomes in a continuous environment. It is argued that under these conditions a quote-driven intermediary market can overcome the limitations of auction approaches. Moreover, such a market obviates the need for strategic behaviour in individual traders thus simplifying their design. Simple adaptive approaches to market-making are shown to be sufficient to obtain competitive outcomes in a relatively stable continuous trading environment.

1. INTRODUCTION

Extended trading periods and market opening hours have led to the consideration of automated market types which allow continuous trading of assets and commodities. In such markets the supply and demand schedules, and likewise the market price, fluctuate continually. This research is an attempt to analyse several well-known types of automated market under fluctuating, though essentially stable, market conditions to determine their relative performance. Computer simulations demonstrate that market type can lead to large deviations in outcome from the point of view of both market efficiency and the individual trader.

Traditionally economists have investigated different market types using analysis of historical data. Another approach has been that of experimental economics in which (usually) human traders participate in market scenarios designed to inform a particular aspect of market performance [8, 2, 5]. Work on experimental economics has been enhanced using computer assisted markets so that it has even been possible to compare computer traders with their human counterparts [3, 1, 6]. However, very little of this research has considered the impact of supply and demand schedules that fluctuate over time. Although many authors have discussed the fact that the competitive equilibrium necessarily changes whenever transactions occur, no systematic analysis of how this may impact market performance has been undertaken.

Given the impact of new technology, particularly the advent of the internet, it seems likely that many market institutions, both old and new, will avail themselves of automated trading environments and even trading agents. There has been an explosion of interest in the design of trading agents with many researchers competing to produce the most effective strategies [6, 9]. Agent designers have had to devise complex trading strategies involving a high investment of intellectual property in order to avoid their agents being exploited. However, one of the key concepts in mechanism design is simplicity, that is, how easy is it for an individual to participate in a market and how transparent are that market's processes. It may be that auction approaches are not sufficiently simple as to encourage participation. One of the main thrusts of this research is to show how a more traditional form of market, one that requires an intermediary, called the market-maker, may offer the simplest alternative for individuals. It does not require them to behave strategically because the market-maker performs the price-discovery function for them.

This research shows, albeit in a simplified and idealised scenario, that intermediaries are an *essential* component within a continuous market environment. If these are market-makers, part of the market infrastructure and regulated, their role is transparent to individual traders. However, in other automated markets, since intermediaries are free to exploit the market inefficiencies undetected, strategic behaviour of individuals is the only protection they have from such exploitation. An automated quote-driven market in which the intermediaries themselves are agents may prove a more attractive proposition than auction-based alternatives.

The paper is organised as follows: section 2 describes the continuous market scenario and the market types investigated; section 3 discusses the issues raised in evaluating continuous markets and presents the metrics used for comparison; section 4 describes the experiments performed and discusses the results; section 5 concludes.

2. A CONTINUOUS MARKET SCENARIO

The scenario consists of a market place in which the traders, i.e., the buyers and sellers, exist for discrete periods of time during which they attempt to trade profitably subject to their limit prices. Because the research interest here is the impact of the market type, strategic behaviour of the individual traders is not considered. That is, the effect of market infrastructure on non-strategic individuals is examined. In the auction-based markets, each trader submits his limit bid or offer, withdrawing it if he leaves the market. In the quote-driven market, each trader checks the market-maker's price and deals subject to his limit and expiration time. These traders are similar to the zero-intelligence constrained (ZI-C) traders of Gode and Sunder [3], except that they submit orders at their limit price, rather than selecting a suitable price at random. The market types considered are as follows:

- **CHA** The periodic clearinghouse or call-market auction: In this market the traders' bids and offers are arrayed and the market clearing price is set at the point of zero excess demand (tatonnement). Intra-marginal orders, i.e., those bids higher than and those offers lower than the clearing price, are matched. This clearing process occurs periodically at every nth time-step (CHA-n).
- **CDA** The continuous double auction: In this market the traders' orders are placed on a limit order book in price and time priority. When an order is submitted, if its price crosses the best order of the opposite type, the orders are matched.
- **QDM** The quote-driven market: In this market, one or more market-makers are obliged to make two-way prices of a fixed spread to traders who can choose whether or not to deal on those prices. Rather than submit an order, each trader checks the market-maker's price and deals subject to his limit and expiration. This paper reports on the case of the single market-maker. In a control case (QDM-1), the market-maker's opening price is the pre-computed competitive equilibrium; in other cases (QDM-1R), the opening price is selected from a uniform distribution between 0 and 2.00. Additional variations include the size of the fixed spread and the reaction of the market-maker's price in response to trader activity (discussed below).
- **CHA-G** The global clearinghouse auction: As CHA above except that time is ignored and all orders are cleared simultaneously. This is a control case that is used to compute the theoretical maximum market surplus available under a given supply and demand schedule as well as the competitive equilibrium price and quantity. It is also used to determine which traders should ideally be successful (intra-marginal traders) and which should not (extra-marginal traders).

In the computer simulation, each of these markets is applied to sets of trader data generated in advance. Each set of data represents a period of 1000 time-steps. The following parameters and distributions are used to generate the trader data: arrival rate (the mean number of traders arriving at each time-step; a Poisson distribution is assumed); duration (the mean duration in time-steps of each trader; again, a Poisson distribution is assumed); buyer-seller (BS) ratio (the ratio of buyers to sellers; a ratio of 0.7 implies that each trader will be a buyer with probability 0.7; a uniform distribution is assumed); price (selected randomly from a uniform distribution between 0 and 2.00). The market conditions are described as relatively stable because the parameters used to generate the data do not vary over the 1000 time-steps.

This parameterised scenario can be used to simulate a wide variety of trading circumstances. For example, a low arrival rate represents a relatively illiquid market while a high rate represents an active one; a long duration implies that traders may not be concerned with dealing immediately whereas a short duration could be used for traders of a perishable resource; the BS ratio is used to simulate differences in demand and supply.

For the market-making agents, a simple parameterised adaptive strategy is used in order that they can adapt their prices in response to the supply and demand they experience. A "reaction" factor causes the agent to move its price every time it trades: whenever it buys its price goes down; whenever it sells its price goes up. The reaction is just a percentage of the agent's fixed spread. For example, if an agent with a reaction factor of 0.25 is making a price of 0.95-1.05 and is sold one unit at 0.95, it will adjust its price to 0.925-1.025 when next asked to quote. Although this adaptive strategy is simplistic, it will be seen that it is reasonably effective in the stable conditions of these experiments.

3. EVALUATING CONTINUOUS MARKETS

Empirical research of market types has usually involved examining the market outcomes over a single trading period or a short series of trading periods. Metrics are used to examine whether the quantity traded reflects that predicted by competitive market theory, and whether and how the prices at which trades take place converge to the competitive equilibrium price; this latter is usually measured by examining a coefficient, α, representing the root mean square "error" in prices over the course of a trading period (i.e., the standard deviation from the competitive equlibrium price). The overall efficiency achieved during a trading period can be estimated as a percentage of the overall profit achieved compared with the maximum attainable under perfectly competitive market conditions.

In the continuous market environment under investigation, individual traders are endowed with a limit price at which they are willing to either buy or sell goods. In contrast to the single trading period experiments in which all traders are allotted their endowments at the start, in these experiments, it is assumed that the traders arrive at some point in time, attempt to trade over a period of time and, if unsuccessful, leave the market. Thus, the supply and demand schedule is fragmented and there are choices to be made about how one evaluates market performance. In the research presented here, although trader activity is temporally fragmented, the underlying supply and demand is relatively stable as discussed above. In this context, a straightforward method of evaluation of market performance is used as follows:

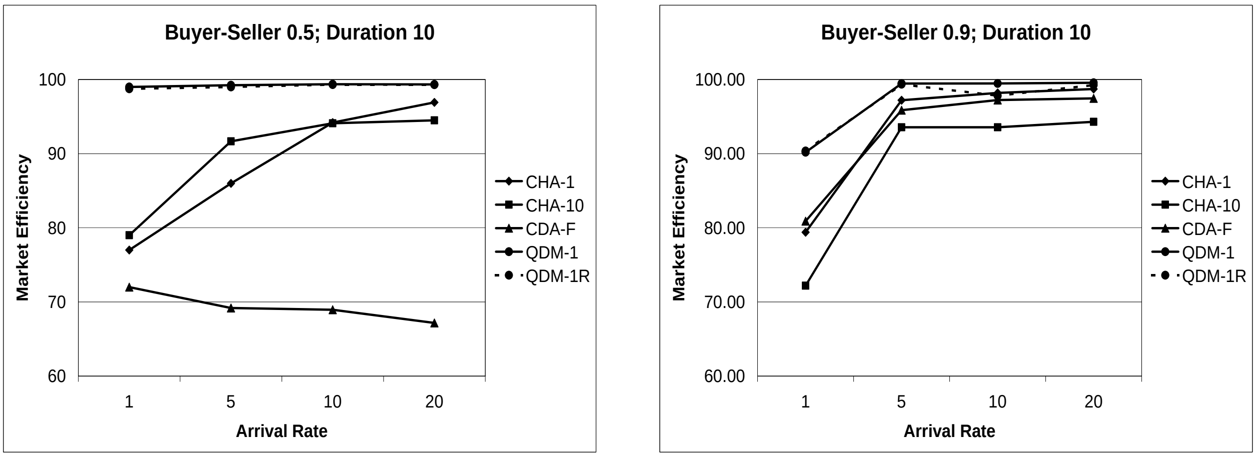

Figure 1: Market efficiency vs arrival rates

Each set of trader data is considered "globally", that is, in isolation without the temporal fragmentation. To do this, the CHA-G market is applied with all traders as if they existed instantaneously. This gives an upper bound on the potential profit extractable from that set of traders and the optimum quantity that should be exchanged. It also determines both an overall competitive equilibrium price and hence which traders would succeed in a perfectly competitive market, *were they all to exist simultaneously.*

Using these figures, the following metrics can be used to evaluate and compare the different markets:

- Efficiency: The percentage of the global profit achieved. Note that in the quote-driven market some of this profit will go to the market-maker(s) and this is included in the total.
- Intra-marginal success: The percentage of traders who succeeded who would also have succeeded in the global market.
- Extra-marginal success: The percentage of traders who succeeded who would not have succeeded in the global market.
- Alpha (α): The root mean square error between each trade price and the global competitive equilibrium price. This metric reflects the standard deviation of trades from the competitive price: a higher metric reflects greater variation in the prices at which trades occur.
- Market-maker profits: The percentage of profit (from total global profits available) extracted by market-makers.

4. EXPERIMENTATION AND RESULTS

A series of experiments were conducted varying the mean arrival rate (1, 5, 10, 20), mean duration (5, 10, 30, 50) and BS ratio (0.5, 0.7, 0.9, 0.95). Each set of data was generated in advance and applied to market types CHA-1, CHA-10, CDA, QDM-1, QDM-1R (the QDM-1R results are averaged over 3 runs). Other investigations were conducted but are not reported in detail.

4.1 Market efficiency

Figure 1 shows the market efficiency obtained for each market type for the full range of arrival rates, a fixed mean duration of 10 and two BS ratios.

The QDM-1 market performs consistently well averaging close to 99% across the whole range of parameter settings. Although for this control case the market-maker's opening price has been fixed at the competitive equilibrium price, it does indicate that, once the market-maker has found that price, its simple adaptive algorithm is sufficient to maintain that level and hence operate at near maximum efficiency. In contrast, in the QDM-1R, in which the market-maker opens with a random price, efficiency was slightly lower. For BS ratios around the 0.5 mark, performance is similar to that of QDM-1; however, the cost of discovering the competitive equilibrium price appears to become significant at higher BS levels and efficiency deteriorates, though the effect is less marked for higher arrival rates. Conversely, the efficiency of both the CHA and CDA markets appears to improve as the BS ratio increases from 0.5 to 0.95.

Both CHA and CDA markets appear to under-perform the QDMs, particularly for BS ratios around 0.5. For example, the CHA-1 market with BS ratio 0.5 and arrival rate 5 manages only 86%. The CDA market has an efficiency averaging only around 70% when the BS ratio is 0.5, even for high arrival rates. Across all market types efficiency tended to increase with arrival rate except in the case of CDA when the BS ratio was around 0.5. In this latter case, more arrivals tended to decrease efficiency though only slightly.

The CDA results demonstrate that this automated mechanism suffers from a severe problem when there are similar numbers of buyers and sellers. It seems that the limit order book often contains only the orders of extra-marginal traders. Thus when an intra-marginal trader submits an order it will often cross with an extra-marginal order, necessarily causing a reduction in market surplus. This effect can be seen in figure 2 which shows that the efficiency gains appear to come from the reduction in the extra-marginal success rates rather than an increase in intra-marginal rates.

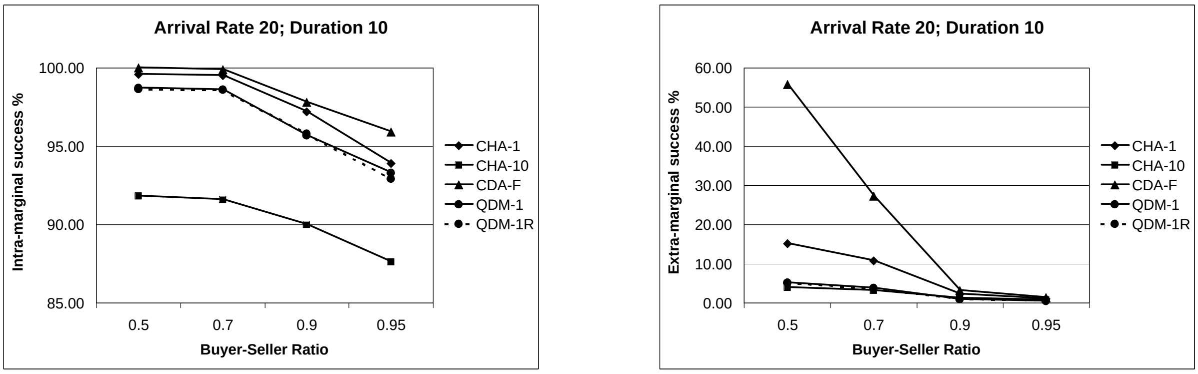

Figure 2: Intra- and extra-marginal trader success rates

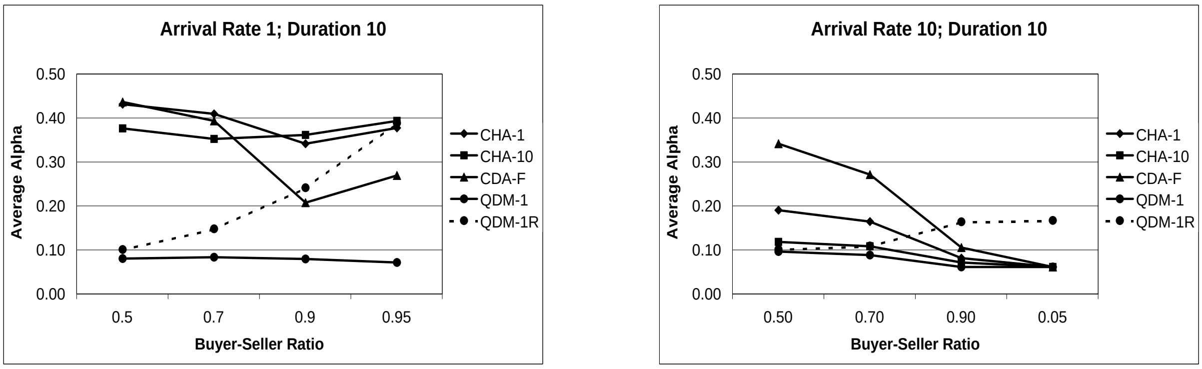

Figure 3: Average alpha values vs BS ratios

There is no doubt that the efficiency of the CDA would be greatly improved were traders to behave strategically. One cause of the CDA's poor performance is the serial nature in which orders have to be placed and processed. There will always be inefficiencies caused by the temporal fragmentation in supply and demand. These problems have not be fully addressed in experimental economics research which tends to focus on single trading periods. The CHA overcomes this problem, to an extent, in that it batches the limit orders and matches them periodically. This has the disadvantage of requiring the traders to wait till the next period before the trade can be processed at the next call (though the CHA-1 market minimises this waiting time). However, these markets still exhibit inefficiencies due to the inability of supply and demand to be carried over once the limit traders expiration time is up. The QDM performance appears to be remarkably robust under a variety of supply and demand profiles. Efficiency is rarely under 95% and it appears that the cause of inefficiencies in the QDM-1R market is mainly the need to discover the correct price. Of course, in the case of the QDM not all the market surplus goes to the traders as will be discussed below; however, if the market-maker's profit is not excessive, the automated QDM appears to work best for non-strategic traders.

4.2 Average alpha

Figure 3 shows the average alpha (α) values for the same datasets as reported above. Again the QDM-1 market produces the best overall results with alpha values averaging below 0.1 under almost all conditions. The QDM-1R market also maintains relatively low alpha values except at the highest BS ratios. Again the QDM-1R performance changes in the opposite direction to that of the CHA and CDA markets in which alpha values tend to decrease as the BS ratio increases. It appears that the average alpha values are quite strongly negatively correlated with overall efficiency.

4.3 Duration

Changes to the average duration of traders had little impact in the CDA or QDM markets. The implication here is that traders usually execute their orders soon after they arrive or not at all.

In the CHA markets, however, the effect was marked in that longer durations tended to increase the market efficiency, particularly for higher periods between the calls. For example, with arrival rate 5, CHA-10 is only 92% efficient when average duration is 10; this increases to 98% when duration is 30, albeit with different datasets. Similarly, an increase in the period between calls tends to decrease efficiency so that CHA-50 achieved only 65% efficiency on the latter dataset. An obvious conclusion to draw here is that to maximise efficiency, periodic call markets need to reflect the mean duration of traders.

4.4 Market-maker profits

Market-maker profits were looked at in terms of the percentage of the market surplus they took for themselves. It is often remarked that the dealer's spread represents his reward for providing the market-making function and so it is interesting to see whether this can be achieved in the stable market conditions that are examined here.

In the QDM-1 market in which the market-maker omnisciently knows the market price at the start, the average percentage obtained is a remarkably stable 7.52% with a standard deviation of only 0.34 over a wide ranging sample of arrival rates and BS ratios. Given that this market type also produces efficiencies rarely lower than 99%, from the trader's perspective such a market appears to practically guarantee 91.5% efficiency. Clearly the market-maker's profits are related to the fixed spread. Keeping the reaction ratio fixed at 0.25, this spread was varied from 0 to 0.25. It was found that increasing the spread to around 0.1 does not affect market efficiency with the market-maker's profit simply reducing the trader's profits correspondingly. Above this level, although the market-maker's profits increased, the number of intra-marginal traders who succeeded started to decline and therefore the overall effect was of lower efficiency.

In the QDM-1R market in which the market-maker's opening price is chosen randomly between 0 and 2.00 the results were more variable. However, taking the results for BS ratios 0.5 and 0.7 together, the market-maker profit averaged 6.98% (with standard deviation 0.89%). As the BS ratio becomes more extreme, the market-maker profits are erratic and may turn into losses. These results reflect the cost of price discovery.

5. CONCLUSION

This paper has reported on the results from computer simulations designed to analyse the performance of automated market types under a variety of continuous trading environments.

From the mechanism design perspective, the automated quote-driven market appears to offer several advantages over the other two types considered. One of the goals of effective mechanism design is "simplicity" [7, 4], and this market type would certainly facilitate the participation of agents by making them easy to design and implement. Trading-agents using a QDM need not have complex strategies but simply trade within their own limits. The market price is also always available from the market-maker. Of course, the benefits to traders of the QDM come at a price—the main cost is the market-maker's profit.

It is important to note that the quote-driven market has a rather unfair advantage over the other automated markets investigated—it is the only market type that allows excess supply or demand to be "carried over" indefinitely in time; this occurs because the market-makers can run both long and short positions. Running positions inevitably incurs some costs which have not been incorporated in this model; neither has the risk involved been considered. But this research has demonstrated the *necessity* of intermediaries to perform such a function. Although intermediaries can equally well exist within the other markets, their privileged role in the QDM rewards them for the risks they are taking and costs they may incur but at the same time allows the market participants the transparency of knowing that they are dealing with an intermediary; this cannot occur in the anonymous market clearing processes of the CDA and CHA.

In future work, the main objective is to examine the impact of more changeable supply and demand conditions as well as looking at the impact of at-market or liquidity traders.

6. ACKNOWLEDGEMENTS

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