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Towards adaptive ex ante circuit breakers in financial markets using human-algorithmic market studies

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Abstract— *Position paper introducing an AI research methodology for investigating dynamics and stability of financial markets. Controlled experiments using an experimental financial marketplace containing humans and adaptive trading agents are performed; with brain activity of human participants captured using an EEG headset. Machine learning is applied to brain and trading data to develop an adaptive multi-agent model of markets that can be optimised for stability using a co-evolutionary GA framework. Specifically, financial market circuit breakers—mechanisms for limiting or halting trading on an exchange—are addressed; a pertinent real-world problem of trans-national importance. Ex post circuit breakers that halt a market after a sudden price swing will be analysed and optimised. Further, ex ante circuit breakers, which are triggered before problems emerge, will be investigated and explored. The development of reliable "anti-crash" trading technology would have globally significant economic, social, and political impact.*

Keywords: Agent Based Modelling, Brain Computer Interaction, Coevolution, Financial Circuit Breakers, Trading Agents

1. Introduction

In 2012 the UK Government's Office for Science published their final *Foresight* report on the future of computer trading in financial markets [1]. The two-year research project, involving 150 leading academics from more than 20 countries, concluded that introducing coordinated circuit breakers may help reduce extreme adverse price instability; such as witnessed during the "flash crash" of May 6, 2010, when the Dow Jones Industrial Average plummeted 5% (wiping approximately $1 trillion in value) in just 5 minutes [2]. Furthermore, it was suggested that the development of new types of ex ante circuit breakers that are triggered *before* problems emerge would be particularly advantageous [1, p.105].

In September 2015, after a volatile August period that saw widespread losses on China's stock markets, the introduction of an ex post circuit breaker was announced [3]. The breaker, designed to halt trading for half an hour when indexes fall by 5%, went live on January 4, 2016. After a sustained market rout, causing the breaker to trip twice in the space of four days, the breaker was suspended; leading directly to the resignation of the chairman of the China Securities Regulation Commission [4].

These events highlight a fundamental problem facing market regulators. Current understanding of the dynamics of financial systems is woefully inadequate; there is simply no sound theoretical way of knowing what the systemic effect of a structural change will be [5]. Therefore, introducing new regulatory policy amounts to little more than trial and error testing. This is a symptom of the dominant economic modelling paradigms of rational expectations and oversimplified equilibrium models; but a solution is possible. It has been compellingly argued that economic systems are best considered through the paradigm of complexity [6]. Agent-based models present a way to model the financial economy as a complex system [7], while the converging traditions of behavioural [8] and experimental [9] economics can address non-rational human behaviours such as overconfidence and fear using controlled laboratory experiments.

This position paper proposes a novel methodological framework for a hybrid approach to modelling financial systems. Section 2 briefly reviews modelling paradigms and the impact of computerised trading on financial markets. Section 3 introduces the proposed framework. Section 4 outlines financial market circuit breakers as an application area for future work. Finally, Section 5 concludes.

2. Background

2.1 Modelling Economic Systems

Classical economics relies on assumptions such as market efficiency, simple equilibrium, agent rationality, and Adam Smith's invisible hand. These concepts have become so strong that they tend to supersede empirical evidence. Consequently, no classical framework exists to understand "wild" market dynamics such as crashes. To ensure more long-run stability, therefore, it is necessary to develop "a more pragmatic and realistic representation of what is going on in financial markets, and to focus on data, which should always supersede perfect equations and aesthetic axioms" [5].

Disturbingly, there are no mature models used to understand and predict issues of systemic risk in the financial markets [10]; leaving policy makers in the dark. While sophisticated mathematical models exist for modelling potential profit and risk of individual trades, there is "no attempt to assemble the pieces and understand the behaviour of the whole economic system... When it comes to setting policy, the predictions of... models aren't even wrong, they are simply non-existent" [7]. "Two particularly illuminating questions about priorities in risk management emerge... First, how much money is spent on studying systemic risk as compared with that spent on conventional risk management in individual firms? Second, how expensive is a systemic-risk event to a national or global economy (examples being the stock market crash of 1987, or the turmoil of 1998 associated with the Russian loan default, and the subsequent collapse of the hedge fund Long-Term Capital Management)? The answer to the first question is 'comparatively very little'; to the second, 'hugely expensive"' [6].

Fuelled by disillusionment with classical economics, there is a trend toward alternative economic modelling paradigms designed to overcome the problems of classical economics: (1) *Agent-based models* potentially present a way to model the financial economy as a complex system, while taking human adaptation and learning into account [5], [7], [6], [11]; (2) *Behavioural economics* addresses the effects of social, cognitive, and emotional factors on the economic decisions of individuals. The focus is on non-equilibrium processes and actions of diverse agents with bounded rationality who may learn from experience and interactions [8]; (3) *Experimental economics* is the application of experimental methods to study economic questions. Data collected in experiments are used to estimate effect size, test the validity of economic theories, and illuminate market mechanisms [9].

2.2 Computer Trading in Financial Markets

In recent years, the financial markets have undergone a profound transformation from a highly regulated human-centred system, to a less-regulated and more fragmented computerised system containing a mixture of humans and automated trading systems (ATS)—computerised systems that automatically select and execute a trade with no human guidance or interference. Today, the majority of trades are executed electronically and anonymously at computerised trading venues where human traders and ATS interact. Homogeneous human-only markets have evolved into heterogeneous human-ATS markets, with recent estimates suggesting that ATS now initiate between 30% and 70% of all trades in the major US and European equity markets [1].

As computerisation has altered the structure of financial markets, so too the dynamics have changed. In particular, trading velocity (the number of trades that occur in unit time) has dramatically increased [1]; stocks and other instruments exhibit rapid price fluctuations ("fractures") over sub-second time-intervals [12]; and wide-spread system crashes occur at astonishingly high speed (e.g., the flash crash saw US market indexes plunge 5% in 5 minutes, and then largely recover over the next 20 minutes [2]). The speed and scale of such system dynamics were unprecedented in the pre-computerisation era. To accurately model financial systems, therefore, it is now no longer sufficient to consider human traders only. It is also necessary to model ATS.

3. A New Modelling Methodology

Here, a novel framework is proposed to model financial systems using a synthesis of experimental economics, behavioural economics, and agent based modelling approaches.

3.1 Real-time human-agent markets

Experimental human-only markets have a rich history dating back to Vernon Smith's seminal—and ultimately Nobel-prize winning—1960's research [9]. Smith demonstrated that financial markets can reach theoretical equilibrium through the market mechanism alone, without further assumptions. Several decades later, it was shown that identical markets containing only adaptive ZIP trading agents can also reach equilibrium [13], and can do so *more efficiently* than human only markets [14]. Using a relatively simple reinforcement learning rule to maximise expected profit, ZIP serves as a minimal model of human trading behaviour and has become a standard tool for financial trading simulations. However, despite this long history, relatively few experiments have been performed using mixed markets containing software trading agents *and* humans; and those that have tend to be discrete in nature (for an extensive review, see [15]).

Real-time human-agent markets add a critical dimension of realism that is missing from discrete trading experiments. ATS act at speeds much quicker than the limit of human reaction times. This disparity has been shown to produce a phase transition such that at time scales faster than human reaction times the market enters a regime of computer-only trading that exhibits ultra-fast fractures [12].

Previous work by the author and collaborators has demonstrated that using real-time markets containing a mixture of human participants and financial trading agents holds promise for understanding real-world financial markets. In particular, it has been shown that moving from discrete-time to real-time trading alters the behaviour and efficiency of markets, suggesting that all previous studies using discrete-time experiments may need to be re-evaluated [15]. It has also been demonstrated that faster financial trading agents can reduce market efficiency; a result that may have significant real-world implications [16]. Finally, it has been shown that when trading agents act at speeds quicker than human reaction times, the market starts to fragment towards agent-only interactions and human-only interactions [17]; a result that supports real-world data [12].

3.2 Brain-data for human behavioural models

To extend the methodology used for previous real-time human-agent markets, brain activity of human traders will be captured during trading experiments using an EEG headset. This technology quantifies real-time electrical brain activity using two dimensions: attention and meditation, and has been used in applications such as controlling adaptive film [18]; and for neuro-adaptive human-computer interfaces [19]. Brain activity data will be captured during times when the market is relatively stable, and during times of extreme volatility (market shocks). Supervised learning methods will be applied to data to build a model of human trading that transitions from logical to more emotional trading behaviour, as market dynamics shift. This approach, akin to the behavioural economics paradigm, will enable a more realistic human-trading model to be developed; and subsequently used within an agent-only market model.

3.3 Coevolution of agents and market

Once an agent-only model has been developed, a competitive coevolutionary genetic algorithm [20], [21] will be used to co-adapt agent models, market structure, and potential regulatory mechanisms. This coevolutionary approach has been successfully applied in discrete agent-only markets; demonstrating the intriguing result that the traditional exchange mechanism (where buyers and sellers have an equal chance of trading) may not be optimal in agent-only markets [22]; although a later result cast some doubt on this [23].

3.4 Open Source Platform

To implement this approach, the author will extend "ExPo: the Exchange Portal", an open-source real-time trading platform for controlled human-agent financial trading experiments [24]. ExPo is a web-application enabling human participants and trading agents to trade over a network. An admin interface, accessible through a web browser, enables the operator to configure experimental variables; including maximum time, supply and demand schedules, number of participants, and agent trading models. ExPo has previously been used to implement real-time versions of discrete trading agents from the literature, and to explore novel Assignment Adaptive (ASAD) trading agents [25]. (For a description of ExPo, see [26].) ExPo will be wrapped in a coevolutionary framework, enabling market mechanisms and trading agents to be automatically adapted using a competitive coevolutionary GA. The extended framework will be released open source; a practice that the author strongly advocates [27].

4. Application: Circuit Breakers

Financial circuit breakers that limit or halt an exchange during times of extreme volatility are used in many major markets. By halting trading during a rapid swing in price, the breaker is designed to stop further movement by "calming" the market. However, this is manifestly not always the outcome. In January 2016, China introduced a circuit breaker that would halt the market for 30 minutes when indexes fall by 5%. The breaker tripped on the first day of trading. But rather than calm the market, the halt in trading caused widespread panic. When trading resumed, further dramatic falls ensued. After a subsequent trip and market halt, the breaker was abandoned and the regulator resigned.

This episode highlights the "irrational" behaviour of market participants and the need for better models of financial markets to test regulatory mechanisms *before* they are introduced into real markets. To achieve this, a series of agent-human financial market experiments will be run under three conditions: (1) a stable market with fixed equilibrium P_0, (2) a shocked market where equilibrium P_0 shifts, and (3) a shocked market containing a simple ex post circuit breaker that halts trading for t seconds after a price swing of ρ percent. Data will be used to test the null hypothesis h_0; that circuit breakers have no effect on market equilibration (defined using Smith's α metric [28]—the root mean squared deviation of transaction prices from theoretical equilibrium, P_0). If h_0 is rejected, then the relationship between t, ρ, and α will be empirically established. Such understanding will immediately offer novel insight into the causal relationship between circuit breakers and market dynamics.

Brain activity data of human participants will be investigated for a change in participants' emotional state—in particular attempting to identify a phase shift in attention and meditation signals—during times of market stress, and during a breaker-triggered market halt. Any changes in trading behaviour that are correlated with a shift in emotional state will be identified and measured. In particular, trading aggressiveness (measured using the proportion and frequency of market orders—those that take the current price; rather than passive limit orders—those that set a target price and wait) will be monitored. Insights into the effects of circuit breakers on the emotional state and corresponding behaviour of traders will be a significant theoretical advance.

To model the emotional behaviour of traders, a reactive "Emo" trading agent will be developed. Emo agents will extend ZIP, such that prevailing market conditions will vary internal ZIP parameters, or shift between "emotional" and "logical" ZIP states. An ensemble of machine learning techniques (neural networks, decision tree learning, reinforcement learning) will be used to fit the adaptive Emo model over data generated during the previously described human-agent experiments. For validation, comparative market experiments will be re-run, replacing human traders with Emo traders. If successful, Emo will be a novel contribution to the literature on experimental and behavioural economics.

Once a validated agent-only (ZIP-Emo) market is available, this will be used within a coevolutionary GA framework to optimise breaker parameters. Using α (and/or other standard metrics, such as profit dispersion and market efficiency [15]) as a metric for market fitness, evolving breakers will be rewarded with high fitness for *low* α (i.e., for equilibration performance), while the market will parasitically co-evolve (exploring agent types, agent parameters, supply and demand schedules, etc.; and rewarded with high fitness for *high* α), in order to pose difficult market scenarios for the breaker to encounter. To counter-balance any coevolutionary asymmetry present within the system, virulence moderation will be employed [21], [29]. This framework should encourage the exploration and discovery of robust breakers.

Finally, ex ante circuit breakers will be explored. It has previously been shown that there is an intriguing correlation between ultra-fast price swing fractures and the 2010 flash crash [12]. Previous experiments have been able to replicate some of the underlying features of the market that may be linked to fractures [17]. This result holds great promise and prompts further investigation. If a causal link between these phenomena can be identified and understood, then it is possible that an early warning system, or adaptive ex ante circuit breaker can be developed. A further line of investigation will consider neuro-adaptive trading interfaces—graphical approaches that use real-time brain data to warn a trader that they are trading on emotion—and their ability to act as an ex ante circuit breaker.

Circuit breakers in financial markets have been studied using agent-based models elsewhere in the literature, e.g., [30]. However, as far as the author is aware, no other study is using real-time agents, and the behavioural and experimental economics methodology proposed here.

5. Conclusion

A coevolutionary multi-agent methodology for modelling financial markets using real-time human-agent financial market experiments has been proposed. An EEG headset captures human brain activity to identify a phase change during periods of market shock. These data are used to fit adaptive behavioural models of human traders, which are integrated into dynamic agent-based market models to explore and optimise ex post and ex ante circuit breakers using a coevolutionary optimisation approach. This research program has potential for great scientific, policy, and financial impact.

References

[1] GO-SCIENCE, "The future of computer trading in financial markets: An international perspective," UK Government Office for Science, London, UK, Foresight Report, Oct. 2012.

[2] SEC & CFTC, "Findings regarding the market events of May 6, 2010," U.S. Commodity Futures Trading Commission and the U.S. Securities and Exchange Commission, Washington, DC, Report, Sept. 30th 2010.

[3] J. Duggan, "China plans stock market 'circuit breaker' to curb volatility," *The Guardian*, 8 Sept. 2015. [Online]. Available: https://www.theguardian.com

[4] Reuters, "China's stock market regulator 'resigns' after circuit-breaker fiasco," *The Telegraph*, 18 Jan. 2016. [Online]. Available: https://www.thetelegraph.co.uk

[5] J.-P. Bouchaud, "Economics needs a scientific revolution," *Nature*, vol. 455, no. 7217, p. 1181, Oct. 2008.

[6] R. M. May, S. A. Levin, and G. Sugihara, "Complex systems: Ecology for bankers," *Nature*, vol. 451, pp. 893–895, Feb. 2008.

[7] J. D. Farmer and D. Foley, "The economy needs agent-based modelling," *Nature*, vol. 460, no. 7256, pp. 685–686, Aug. 2009.

[8] D. Kahneman, *Thinking, Fast and Slow*. New York, NY: Farrar, Straus and Giroux, 2011.

[9] V. L. Smith, *Papers in Experimental Economics*. Cambridge, UK: Cambridge University Press, 2006.

[10] D. Cliff and L. Northrop, "The global financial markets: an ultra-large-scale systems perspective," UK Gov. Office for Sci., London, Foresight Driver Review—The Future of Computer Trading in Financial Markets—DR4, Aug. 2011.

[11] J. D. Farmer and S. Skouras, "An ecological perspective on the future of computer trading," UK Gov. Office for Sci., London, Foresight Driver Review—The Future of Computer Trading in Financial Markets—DR6, Aug. 2011.

[12] N. Johnson *et al.*, "Abrupt rise of new machine ecology beyond human response time," *Scientific Reports*, vol. 2, no. 2627, pp. 1–7, Sept. 2013.

[13] D. Cliff and J. Bruten, "Minimal-intelligence agents for bargaining behaviours in market-based environments," Hewlett-Packard Labs., Tech. Rep. HPL-97-91, Aug. 1997.

[14] G. Tesauro and R. Das, "High-performance bidding agents for the continuous double auction," in *Proc. ACM Conf. Electron. Commerce*, 2001, pp. 206–209.

[15] M. De Luca, C. Szostek, J. Cartlidge, and D. Cliff, "Studies of interactions between human traders and algorithmic trading systems," UK Gov. Office for Sci., London, Foresight Driver Review—The Future of Computer Trading in Financial Markets—DR13, Sept. 2011.

[16] J. Cartlidge, M. De Luca, C. Szostek, and D. Cliff, "Too fast too furious: Faster financial-market trading agents can give less efficient markets," in *Proc. 4th Int. Conf. Agents & Artificial Intell. (ICAART)*, vol. 2, Vilamoura, Portugal, Feb. 2012, pp. 126–135.

[17] J. Cartlidge and D. Cliff, "Exploring the 'robot phase transition' in experimental human-algorithmic markets," UK Gov. Office for Sci., London, Foresight Driver Review—The Future of Computer Trading in Financial Markets—DR25, Apr. 2012.

[18] M. Pike, R. Ramchurn, S. Benford, and M. L. Wilson, "#scanners: Exploring the control of adaptive films using brain-computer interaction," in *Proc. 2016 CHI Conf. Human Factors in Computing Syst.*, Santa Clara, CA, May 2016, pp. 5385–5396.

[19] A. Girouard *et al.*, "From brain signals to adaptive interfaces: Using fNIRS in HCI," in *Brain-Computer Interfaces*, S. D. Tan and A. Nijholt, Eds. London: Springer, 2010, pp. 221–237.

[20] J. Cartlidge and S. Bullock, "Combatting coevolutionary disengagement by reducing parasite virulence," *Evol. Computation*, vol. 12, no. 2, pp. 193–222, 2004.

[21] J. Cartlidge and D. Ait-Boudaoud, "Autonomous virulence adaptation improves coevolutionary optimization," *IEEE Trans. Evol. Comput.*, vol. 15, no. 2, pp. 215–229, 2011.

[22] D. Cliff, "Explorations in evolutionary design of online auction market mechanisms," *Electron. Commerce Research and Applicat.*, vol. 2, no. 2, pp. 162–175, 2003.

[23] ——, "Zip60: Further explorations in the evolutionary design of trader agents and online auction-market mechanisms," *IEEE Trans. Evol. Comput.*, vol. 13, no. 1, pp. 3–18, Feb. 2009.

[24] J. Cartidge *et al.*, "ExPo: The Exchange Portal." [Online]. Available: http://sourceforge.net/projects/exchangeportal

[25] S. Stotter, J. Cartlidge, and D. Cliff, "Exploring assignment-adaptive (ASAD) trading agents in financial market experiments," in *Proc. 5th Int. Conf. on Agents & Artificial Intell. (ICAART)*, vol. 1, Barcelona, Spain, Feb. 2013, pp. 77–88.

[26] ——, "Behavioural investigations of financial trading agents using Exchange Portal (ExPo)," in *Trans. Computational Collective Intell.*, 2014, vol. 17, pp. 22–45.

[27] J. Cartlidge and D. Cliff, "Comparison of cloud middleware protocols and subscription network topologies using CReST, the cloud research simulation toolkit," in *Proc. 3rd Int. Conf. Cloud Computing & Services Sci. (CLOSER)*, Aachen, Germany, May 2013, pp. 58–68.

[28] V. Smith, "An experimental study of comparative market behavior," *J. Political Economy*, vol. 70, pp. 111–137, 1962.

[29] J. Cartlidge and S. Bullock, "Caring versus sharing: How to maintain engagement and diversity in coevolving populations," in *Proc. 7th Eur. Conf. Artificial Life (ECAL)*, Dortmund, Germany, Sept. 2003, pp. 299–308.

[30] S. J. Leal and M. Napoletano, "Market stability vs. market resilience: Regulatory policies experiments in an agent-based model with low- and high-frequency trading," Lab. Econ. Manage. (LEM), Sant'Anna School of Advanced Studies, Pisa, Italy," Work. Paper, Apr. 2016.