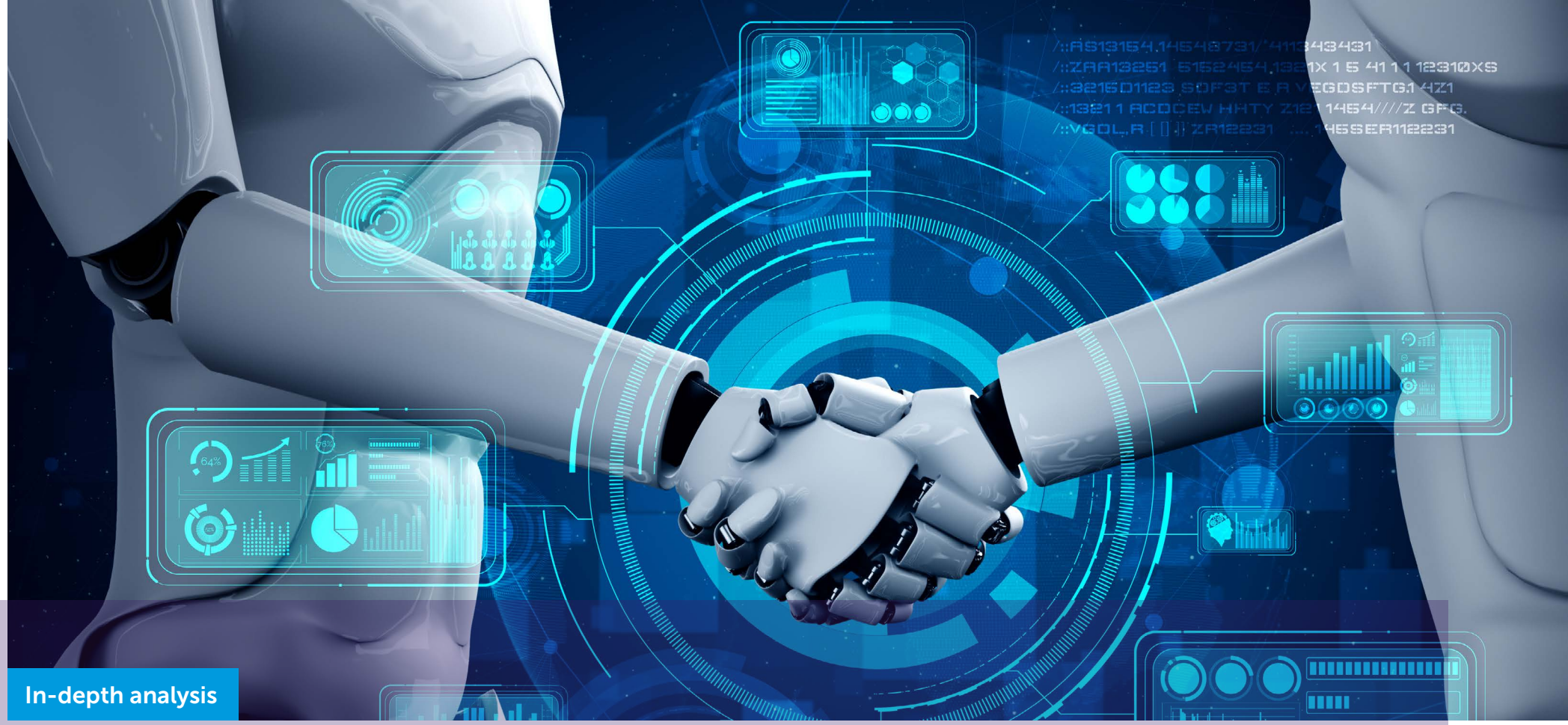

In-depth analysis

Algorithmic collusion in capital markets

Giving central priority to the market's interest

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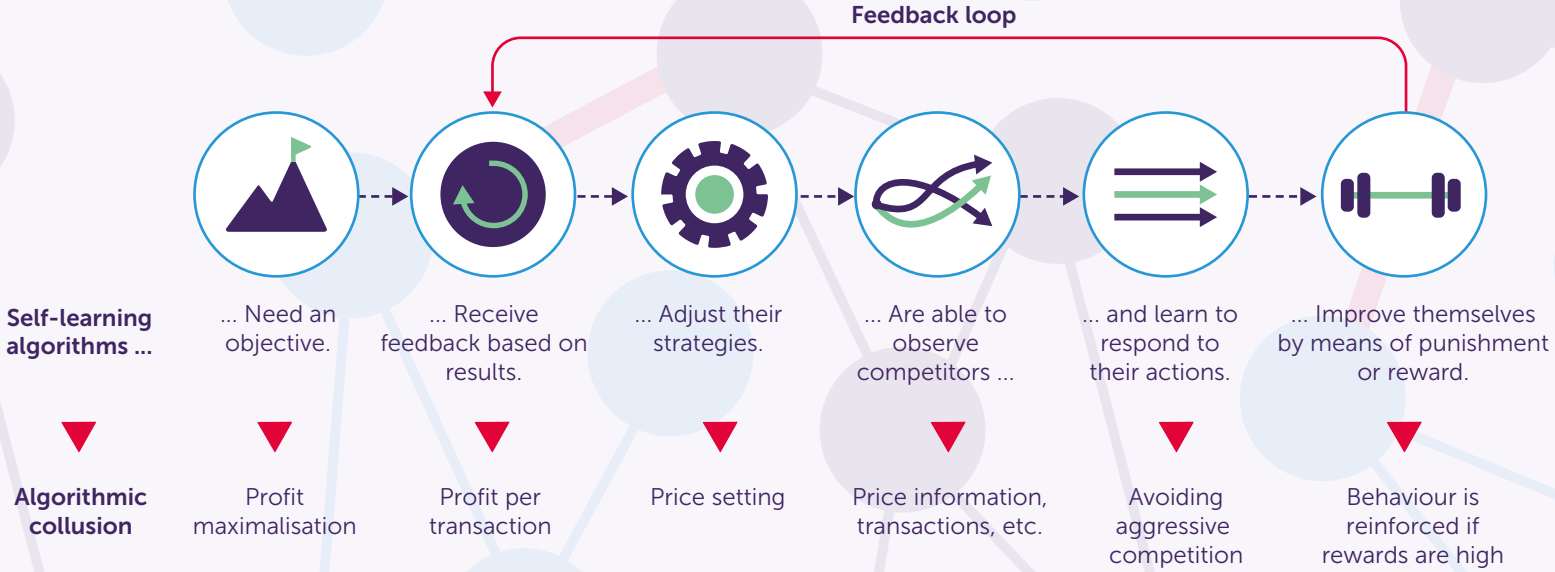
Visual summary
Algorithmic collusion in capital markets

Algorithmic collusion: what is it and how does it work?

This is it ...

Some algorithms are **self-learning**: they can learn from their own behaviour, so as always to take the best action in a given situation. That enables them to improve constantly. If these algorithms **cooperate** with each other, they can **jointly pursue the most advantageous action**: for example, the highest possible joint profit. That is known as **algorithmic collusion**: tacit collusion by algorithms. This type of market manipulation is potentially **harmful**.

... and this is how it works:



Contents

Introduction

Capital markets support the real economy and are constantly changing. Capital markets support the economy if they are efficient, robust and resilient. However, market manipulation, for example, can cause capital markets to fail. The public interest then comes under pressure. Laws and regulations aim to address these types of risks and to promote fair, orderly and transparent trade. The AFM supervises these laws and regulations. We look at whether compliance by market parties actually leads to the higher goal of efficient, robust and resilient markets. This is not static analysis. Capital markets are constantly changing. We therefore continually question whether the public interest in well-functioning markets, or market interest, is served. . And whether market participants take their responsibility, whether legislation is still adequate and whether our method of supervision needs to be adjusted. Digitalisation in particular is prompting rapid changes, different market outcomes and new risks.

Far-reaching digitalisation makes capital markets more accessible than ever, but it also creates new challenges for market parties and regulators. An important trend is the increase in the use of artificial intelligence (AI) in trading algorithms. [1] Recent technical developments in the field of AI make it possible to make these algorithms increasingly smarter and even self-learning. Human interventions are increasingly fading into the background. Academic research has taught us that self-learning algorithms of different parties can enter in some form of interaction with each other, which shows characteristics of tacit collusion. This risk also applies to capital markets. The interaction of these complex trading algorithms can also lead to non-competitive outcomes and excessive costs for end users of capital markets.

In this analysis, we discuss ways to approach new risks, such as algorithmic collusion. Chapter 1 puts capital markets in the broader context of a free-market economy and takes a bird's-eye view of modern capital market functioning. Among other things, we discuss the developments in the field of algorithms. In Chapter 2 we explain what we mean by good market functioning based on the concept of giving central priority to the market's interest. Finally, Chapter 3 considers algorithmic collusion in more detail. This leads to the conclusion that we primarily expect market participants to consider the risk of algorithmic collusion when they use advanced trading algorithms and act on them to to eliminate this risk. Further cooperation between national and international competition authorities, capital market supervisors and (possibly) AI supervisors is also advisable. Depending on developments and behaviour in the market, it will need to be considered in due course whether laws and regulations in this area also need to be tightened.

1 'Machine Learning in Algorithmic Trading', AFM, March 2023.

01 Modern capital markets

The public interest of capital markets is to facilitate the price formation process of financial products and to enable risk and capital allocation. Important features of our economy are enterprise-based production and the role of competition. Enterprise-based production means that there is freedom to decide what, how and how much is produced for the market. As a result, entrepreneurs have to anticipate future demand, which is risky. Competition and innovation create a selection process in which the least efficient producers have to compete against the most efficient producers. This reduces costs and increases efficiency. This ultimately benefits social well-being The price – a purely quantitative standard – is leading in this. Capital markets are ideally suited to process large amounts of information into a price and thus facilitate the price formation process. In capital markets, supply and demand of capital come together, which leads to a trade-off between risk and return. This results in a price that makes it possible for both buyers and sellers to make decisions for the future, which leads to optimal capital allocation. Capital markets can also hedge risks, for example with regard to fluctuations in interest rates, exchange rates or future prices of commodities.

Social developments have a direct impact on the capital markets, which only increases the importance of proper market functioning. Think of themes such as financing innovative companies and making the economy more sustainable. This growing importance is therefore also partly reflected in the European Union's plans in the field of the Capital Markets Union (CMU). The CMU aims to strengthen European capital markets, make the European economy more resilient and support the financing of the European Green Deal and Digital Agenda. [2] The idea is that large and vital capital markets make it easier for companies to raise capital for investments in innovation and sustainability. Compared to other countries within the European Union, the Netherlands has relatively large capital markets, partly due to pension funds and a substantial financial sector.

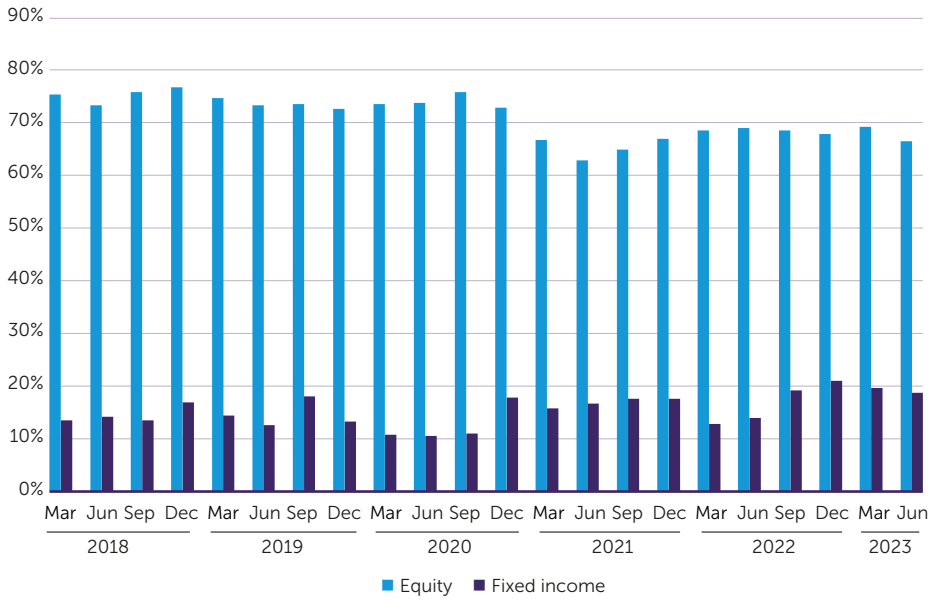
1.1 More complex market structures in times of digitalisation

Capital markets are built on a complex, high-tech infrastructure and trading is increasingly based on algorithms. Most trading takes place on electronic trading platforms where potential buyers and sellers find each other by matching bid and ask prices. These buyers and sellers publish bid and ask prices in an order book, where prices are established on the basis of predetermined logic, or a 'matching algorithm'. [3] Where historically trading took place between traders on physical trading floors – such as in Amsterdam at Beursplein 5 – nowadays the vast majority of trading is automated in some way. This automation ranges from only the communications between traders and the trading platform (electronic trading) to the fully autonomous initiation and execution of buying and selling decisions (algorithmic trading). Depending on the market, virtually all trading is done electronically and up to 80% of trading is done in an algorithmic manner (see Figure 1). Much of the liquidity in capital markets is determined by this algorithmic trading. Liquidity is a crucial concept in capital markets (see Text box 1).

2 'What is the capital markets union?', European Commission.

3 'About Matching Engines', Nasdaq.

Figure 1. A large part of trading on Dutch trading platforms is done by means of algorithms.



Source: AFM

Many trading platforms have designated market makers who play a major role in the proper functioning of capital markets. Market makers are specialised traders who play a crucial role in capital markets worldwide using complex technology. [4] By ensuring that bid and ask prices are always available against which other users, such as pension funds or other investors, can trade, market makers provide liquidity. Depending on market conditions, they also determine the level of trading costs.[5] In addition to technology and human capital, the functioning of market makers is highly influenced by laws and regulations. An example of this concerns rules around the relationship between market makers and trading platforms. In order to guarantee stable liquidity, requirements are set for the agreements between market makers and trading platforms, for example the obligation to offer prices at least half the time.

4 The population licensed proprietary traders in Amsterdam, which is supervised by the AFM, is the largest within the European Union and originates from the Amsterdam options trade.

5 Trading fees include, for example, the spread (difference between bid and ask prices) and transaction fees.

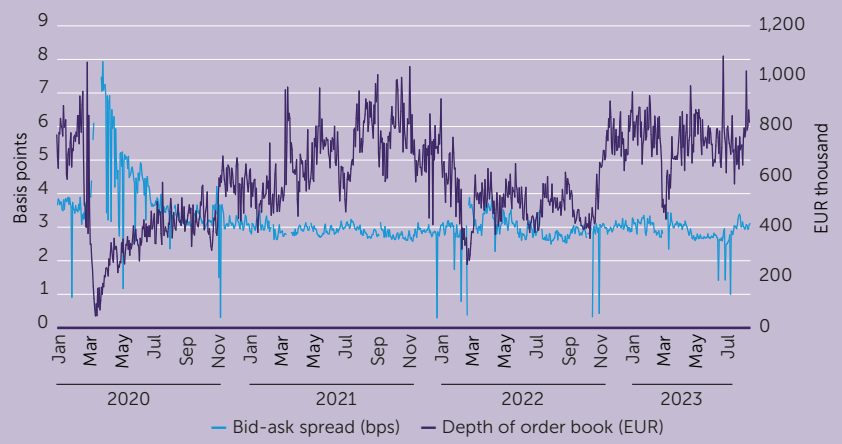
This is laid down in technical standards within the Markets in Financial Instruments Directive (MiFID II/RTS 8). Another example is capital requirements. Capital requirements serve as a buffer and are important for the stability of capital markets, for example in times of increased volatility. They are laid down, among other things, in the Investment Firm Directive (IFD) and the Investment Firm Regulation (IFR).[6]

Text box 1 Liquidity in capital markets

The primary function of capital markets, efficient price discovery, is based on sufficient liquidity. Liquidity is the extent to which buyers and sellers can open or close positions without changing the market price (too much). The higher the liquidity, the easier (large) transactions can take place at prevailing market prices. The interplay of various market participants, both liquidity makers and liquidity takers, with different strategies and risk tolerance, ensures a liquid market. Liquidity is more than just an average high transaction volume or average low spread (the difference between the highest bid price and lowest ask price). More importantly, under all circumstances, even the most volatile, buyers and sellers can trade at the then-current market price. In practice, specific circumstances play an important role, which means that markets that are liquid in normal circumstances can react very differently in times of stress. When the severity of the coronavirus crisis became clear in March 2020, an important part of the order book was dropped (see Figure 2). Liquidity makers that remain active in these conditions can benefit from increased spreads.

6 'Introduction of IFR/IFD', DNB.

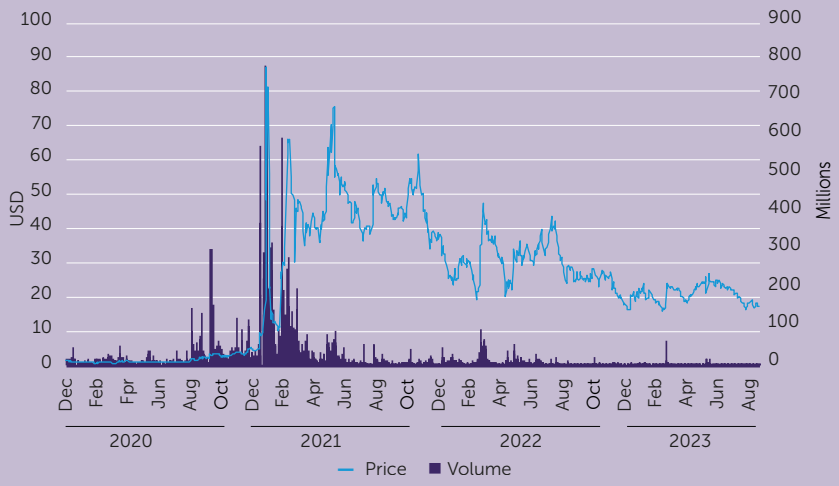
Figure 2. Increased spreads (left axis) and decreased depth of the order book (right axis). Averages over a subset of AEX shares.



Source: AFM

Ample liquidity and the continuous availability of trading platforms are important but insufficient conditions for proper market functioning. Liquidity statistics such as trading volumes, spreads and the number of active players are easily measurable, as is the *downtime* of trading platforms, i.e. the time when trading unintentionally and unexpectedly stops. These are obviously important characteristics that indicate whether the primary market function (facilitating trade) is in order, but ultimately more is needed for preferred market outcomes. Consider, for example, the Gamestop case [7] where stock trading was heavily influenced by social media activity. Trading volumes reached record highs in early 2021 (see Figure 3). Still, friend and foe agreed that the outcomes, including shutting down commerce for consumers,[8] were not immediately to be classified as what you expect in a well-functioning market that leads to correct pricing. This case shows how the use of social media affects market forces. The AFM is alert to these kinds of new developments and carefully assesses the behaviour of all market participants involved.

Figure 3. Gamestop (NYSE) price and volumes at record highs.



Source: Bloomberg

Not only market makers but the majority of all market participants use trading algorithms. From simple pieces of software that automate relatively simple, manual processes to complex *machine learning-based* models that process large amounts of market data and execute buy and sell orders at high speed, fully autonomously. A distinction is made between *execution algorithms* and *trading algorithms*. Execution algorithms only execute orders based on an algorithm and the decision to trade lies elsewhere. If the trading decision is also part of the algorithm, we refer to the algorithm as a trading algorithm. Another distinction is made based on the speed at which algorithms work, where very fast trading algorithms (High Frequency Trading, HFT) are involved. These HFT algorithms operate on a scale of nanoseconds (billionths of a second). For the different types of algorithmic action, a distinction is also made in laws and regulations, although the implications are limited. As soon as

7 'AFM Market Watch 3 Investing and social media in light of GameStop', AFM, June 2021.
8 'Geen onwettigheden, wel meer transparantie gewenst bij handelsbeperkende maatregelen beleggingsondernemingen', AFM, March 2021.

traders use algorithms that determine the characteristics of an order themselves,[9] they are obliged to comply with certain laws and regulations, for example, in testing algorithms or an acute shutdown in case of an unexpected event by means of a so-called *kill switch*.

1.2 Algorithmisation affects the orderly functioning of capital markets

Digitalisation and internationalisation create new risks for the orderly functioning of capital markets. Due to algorithmisation, the role of technology is growing and trading is becoming increasingly complex. Market participants say they use algorithms to provide liquidity more efficiently and thus make capital markets more efficient. But that is difficult to assess. Liquidity in European capital markets seems to be under pressure. Compared to Asia and the United States, European capital markets are shrinking, spreads are barely decreasing and trading volumes are lagging behind.[10] In addition, the rapid developments in the field of artificial intelligence (AI) result in an increase in potentially autonomous black box trading algorithms that put pressure on the orderly functioning of capital markets. Take, for example, the 2022 flash crash in European stocks where the consequences of a *fat finger error* were magnified by algorithms.[11,12] In the wake of internationalisation and fragmentation of capital markets, new forms of market abuse are emerging that are difficult to detect and address.

Most advanced algorithmic traders use machine learning techniques on a large scale. In a recent study, we examined the use of machine learning in algorithmic trading.[13] This showed that machine learning is widely used in traders' trading algorithms. The traders surveyed, who have a Dutch proprietary trading license (HER[14]), use machine learning in 80% to 100% of algorithmic trading of stocks and derivatives, usually when predicting the market price. Up to 1,000 different data points are used to arrive at a solid prediction, for example of the price one second into the future. The study also shows that terminology matters. When asked directly, market participants do not explicitly mention machine learning as part of their trading algorithms, while machine learning is mentioned as important input for the trading algorithms. To avoid confusion, the AFM uses the term 'machine learning-based trading algorithm' to refer to trading algorithms that use (the output of) machine learning models. A machine learning-based trading algorithm can use machine learning implicitly or explicitly.

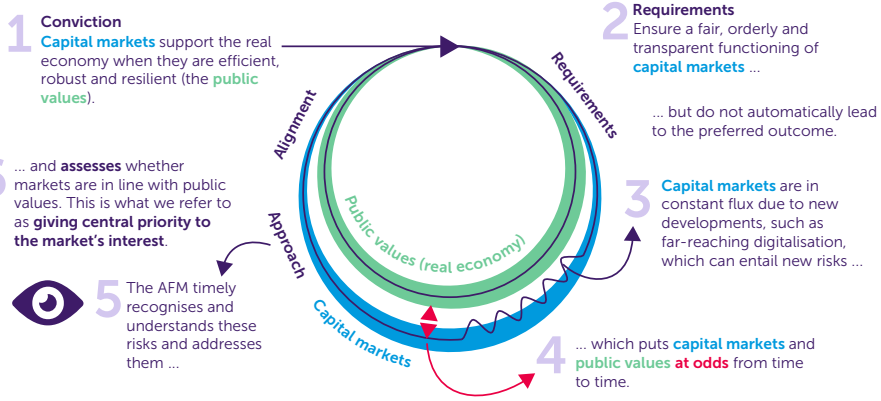
9 Such as the price, the size and how an order should be executed.
10 'Equity-Market Liquidity Is Leaving Europe', AFME, June 2023.
11 'AFM Market Watch 8 Algorithmic trading', AFM, March 2023.
12 Or the 2010 flash crash where the use of algorithms contributed to chaos in the US stock market. See 'Findings Regarding the Market Events of May 6, 2010', SEC, September 2010.

13 'Machine Learning in Algorithmic Trading', AFM, March 2023.
14 Handelaren voor Eigen Rekening

02 Testing proper market functioning

Laws and regulations that ensure fair, orderly and transparent trading are an elaboration of the aim for well-functioning markets. Capital markets are part of the free-market economy but are among the most regulated markets because of their high impact on the economy. Capital markets in Europe are subject to extensive laws and regulations, such as the Markets in Financial Instruments Directive (MiFID II) and the Market Abuse Regulation (MAR). In the Netherlands, these regulations are elaborated in the Financial Supervision Act (Wft). Many of these laws and regulations aim to make markets as efficient (1), robust (2) and resilient (3) as possible. Efficient (1) means that markets function at the lowest possible cost, both in terms of money (trading costs) and time (speed). Robust (2) means that markets can withstand disruption to a certain extent, for example in times of uncertainty or if a large market player gets into trouble. After all, resilience (3) means that markets continue to function even when a fundamental change has taken place. These are all three characteristics that make capital markets functional to support the economy and thus support the public interest of proper functioning capital markets, i.e. the market's interest. These characteristics, or economic goals, are translated into concrete requirements that aim to promote proper market functioning. In this way, public values are translated into clear rules (see Figure 4). The specific legal requirements are often formulated in terms of fairness, orderliness and transparency.

Figure 4. Supervision of capital markets: from conviction and requirements to a preferred market outcome.



Fair, orderly and transparent are umbrella concepts. The umbrella concepts fair, orderly and transparent share the connotation 'according to the law'. This connotation means that they are concepts that are (only) interpreted in relevant laws and regulations. Furthermore, fair means as much as (1) 'free from prejudice or injustice', orderly (2) means 'neat, tidy and well organised' and transparent (3) 'all information visible and immediately available'. These are concepts that describe how trade must function 'according to laws and regulations' and cannot be seen in isolation from one another. For example, fairness and orderliness cannot exist without transparency (e.g. prohibition of market abuse) and fairness and orderliness intermingle and are sometimes in conflict (for example, when the market is shut down for the sake of financial stability – which affects different traders and investors differently).

Requirements set by legislators do not automatically lead to preferred market outcomes. In an ideal, manufacturable world, a good balance between legal requirements leads to capital markets that are efficient, robust and resilient. However, in a changing world, for example under the pressure of digitalisation and internationalisation, the optimal balance is not an automatic given. It is sometimes necessary to make adjustments, because both the public values of efficient, robust and resilient capital markets and the requirements can be at odds with each other. For example, laws and regulations make markets fairer, more orderly and more transparent on the one hand. On the other hand, regulation aimed at making markets more robust can lead to barriers to entry leading to concentrated markets, possibly structural market power of a few market participants and too little competition, which reduces efficiency. Finding the right balance between fair, orderly and transparent, and recognising, understanding and addressing these risks is part of our approach (see Figure 4).

2.1 Focusing on outcomes where the market's interest is central priority

Our goal as market supervisor is to keep an eye on whether the actual market functioning still corresponds to public values, as intended by the legislator. If the deviation becomes too large, our role is to challenge the new situation and adjust it if possible. As a supervisory authority, we feel responsible for finding the right balance between the various legal requirements. To this end, we test the actual market outcome against the preferred market outcome. The starting point is the public interest of proper market functioning, as intended by legislators. In other words, we focus on the market's interest: the test of whether compliance with legal requirements, such as fairness, orderliness and transparency, does indeed lead to the most efficient, robust and resilient way of serving the real economy. Part of this test is the call to market participants whether the services they are providing and/or the revenue model are in line with the public values of efficient, robust and resilient capital markets. A concrete example is the question of whether the liquidity provided by market makers actually makes markets more efficient and thus serves the real economy as well as possible. The fact that compliance with laws and regulations from a narrow perspective does not automatically lead to the preferred outcomes can be illustrated by an example that is receiving increasing attention from regulators and academics, namely the risk of algorithmic collusion.

03 Case: algorithmic collusion

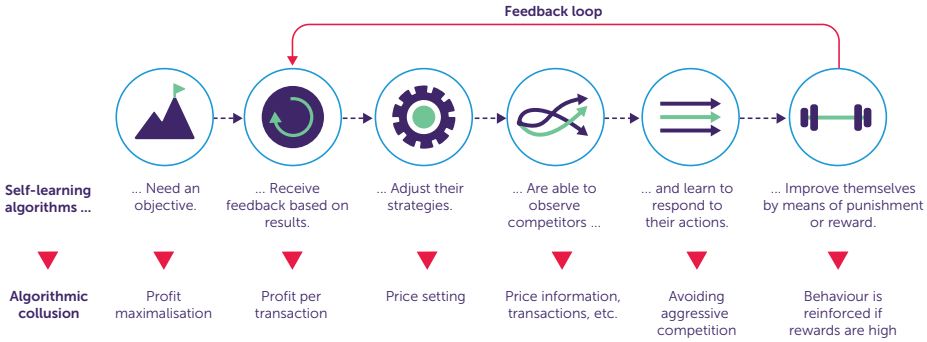
Tacit collusion in capital markets leads to suboptimal outcomes for end users. Collusion is a secret, illicit form of cooperation. Collusion occurs when parties align their behaviour to increase joint profits at the expense of third parties. Collusion is undesirable because it leads to reduced efficiency and reduces general prosperity. Competition authorities are monitoring this. Tacit collusion is an implicit form of collusion, in which the parties do not make explicit agreements. A well-known example of tacit collusion in capital markets occurred on the NASDAQ, where market makers artificially held spreads between bid and ask prices high until 1996. They had not made explicit agreements on this, but when issuing prices they adhered to a certain convention that was unfavourable to end users. Tacit collusion is difficult to distinguish from normal competitive behaviour and difficult to prove, making it harder to address.

Due to the developments in the field of artificial intelligence - and more specifically reinforcement learning - there is a risk of algorithmic collusion. Algorithms based on reinforcement learning are able to learn by *trial and error* from their own behaviour and determine the best course of action in a given situation.[15] Studies show that this type of self-learning algorithm can develop in such a way that it learns to work together to make joint profit (and therefore own profit) as high as possible or to manipulate the market in any other way [16] (see Figure 5). Since no explicit agreements are made and algorithms based on artificial intelligence are naturally a black box, they are potentially very risky. If these algorithms are used to act autonomously, it may not be clear even to the owner of an algorithm that there is in fact collusion.

15 In many (digital) markets other than capital markets, advanced pricing algorithms play a major role. Several competition authorities, including the Authority for Consumers and Markets (ACM), indicate that personalised pricing and algorithmic collusion are a very major concern. However, demonstrating the harmful effects is a major challenge. Concentration and market power of a few parties such as the well-known big-tech platforms or specialised providers of pricing software increase the risks. See 'Algorithmic competition', OECD, 2023.

16 See for example 'Algorithmic Pricing and Liquidity in Securities Markets', Colliard, Foucault, Lovo, October 2022 or 'Algorithmic Collusion in Electronic Markets: The Impact of Tick Size', Cartea, Chang, Penalva, May 2022.

Figure 5. Algorithmic collusion: how algorithms learn to work together

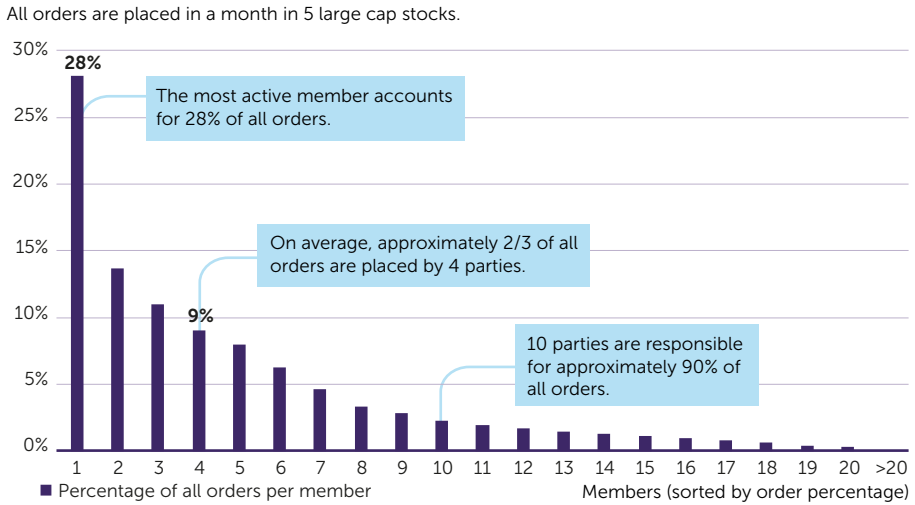


Algorithmic collusion is made possible by market concentration, transparency and frequent interaction. Although there is currently little empirical evidence for algorithmic collusion in capital markets, there is a lot of academic evidence that algorithms using reinforcement learning are capable of tacit collusion. The following ingredients increase the possibility of algorithmic collusion. First, the number of participants plays an important role, or the degree of concentration. The fewer participants, the easier collusion can be established. Second, transparency is an important technical condition for algorithmic collusion. Only by using competitors' prices can algorithms learn to work together. Third, algorithms need repeated interaction to learn to collude, with each interaction yielding a certain profit in itself. It is precisely these conditions that make capital markets particularly susceptible to algorithmic collusion.[17]

17 See for example 'Machine Learning, Market Manipulation and Collusion on Capital Markets: Why the "Black Box" Matters', Azzutti, Ringe, Stiehl, January 2022.

In capital markets, there is a risk of algorithmic collusion. Capital markets are by nature transparent and intended for frequent and repeated interaction with competitors. In the most liquid capital markets, trading is done millions of times a day with the majority being executed by (HFT) algorithms. Also part of frequent interaction is the relative homogeneity of capital markets and the great interconnectedness of international, fragmented markets. Laws and regulations are aimed at ensuring this transparency and liquid trading. However, along with frequently high technology and staff costs, laws and regulations also create barriers to entry. As a result, in many capital markets trading is often dominated by a few members who account for most of the trading (see Figure 6).

Figure 6. Trading on Euronext Amsterdam is dominated by a few members.



Source: AFM

The current legal requirements may not be sufficient to prevent algorithmic collusion. The harmful effects of algorithmic collusion are difficult to demonstrate. On the one hand, it is often indistinguishable from normal competition and there is uncertainty as to whether the existing toolbox of competition authorities is sufficient to address algorithmic collusion.[18] On the other hand, algorithms based on artificial intelligence are complex and developments in this area are progressing rapidly. Demonstrating malicious intent or other unacceptable behaviour of market participants is therefore difficult to prove. Various articles in MiFID and MAR explicitly set requirements for algorithms and *governance* when using algorithms, such as requirements regarding the level of knowledge about one's own algorithms and rules for testing algorithms. Self-assessment and monitoring have an important role in this. First, market participants must be aware of the risk of algorithmic collusion and act accordingly to exclude it. However, even if participants comply with all laws and regulations, the interaction between algorithms can still lead to an undesirable outcome. Depending on developments, it must be examined whether the laws and regulations in this area also need to be tightened and, for example, additional requirements regarding testing and responsible use of AI should be set.

Countering market power and unfair competition through algorithmic collusion is in the public interest. The profits that can be made using algorithmic collusion come at the expense of the efficiency of capital markets. Not only are end users shortchanged by excessive trading costs, confidence in capital markets is also affected. Even though the extent of the potential damage is difficult to estimate for now and end users may only lose a little with each transaction, the market as a whole is being shortchanged. Thus, the possibility of algorithmic collusion harms the public interest.

A successful strategy to address the disruption of market interest has several angles that concern market participants as well as regulators and supervisory authorities. It is important that all parties involved play their part so that together we ensure proper market functioning. We observe four required actions. First, a successful approach requires an awareness among market participants that the risk of tacit collusion can occur when adopting increasingly sophisticated trading algorithms. We expect market participants to understand this risk and to actively intervene to prevent this risk from materialising. This starts by recognising the responsibility for a controlled use of artificial intelligence, including the possible consequences of interacting with other algorithms. This allows market participants to take explicit responsibility for the market's interest. Certain core principles from

18 'Prijsalgoritmes, machine learning en mededinging - KVS Preadviezen 2020', KVS, December 2020.

the proposed European AI regulation may serve as a guideline, such as explainability and human supervision.[19] Second, as a supervisory authority, we are further exploring the use of AI in trading algorithms and detecting new forms of market disruption. We are extending our knowledge in this area through new partnerships, such as the collaboration with the Alan Turing Institute and the University of Oxford in England.[20] For example, we recently conducted a study based on order data into the most important predictors of the behaviour of trading algorithms, in order to gain a better insight into the functioning of trading algorithms.[21] Third, further cooperation between national and international competition authorities, capital market supervisory authorities and (possibly) AI supervisory authorities is on the agenda.[22] Fourth, depending on developments, it must be examined whether legislation and regulations in this area also need to be tightened.

19 'EU AI Act: first regulation on artificial intelligence', European Parliament, July 2023.
20 'Pilot with authority for the financial markets', The Alan Turing Institute, July 2023.
21 'Statistical Predictions of Trading Strategies in Electronic Markets', Cartea, Cohen, Graumans, Labyad, Sánchez-Betancourt, Veldhuijzen, May 2023
22 A good example of cooperation between regulators in the field of digital activities is the Digital Regulation Cooperation Platform (SDT).

Any questions or comments about this publication?

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