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Collusion by code or algorithmic collusion? When pricing algorithms take over

Lea Bernhardt and Ralf Dewenter

Department of Economics, Helmut-Schmidt-University, Hamburg, Germany

ABSTRACT

As algorithmic pricing becomes more widespread, the discussion about the extent to which the use of algorithms results in an increase of collusion also intensifies. While some scholars argue that algorithms are able to collude on their own (algorithmic collusion), others claim that only the use of code to enforce collusion (collusion by code) is a serious threat. In this paper, we discuss both scenarios as well as the conditions under which collusion is likely to occur. As detection and prosecution seems rather challenging, we also discuss possible remedies. These include statistical analyses of market data, an increase in trained staff for competition authorities or even a general ban of specific classes of pricing algorithms. While current competition law seems to be prepared to tackle current issues, it might be adapted for possible future challenges, in case that autonomous algorithms become greater concerns in the future.

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1. Introduction

In April 2011, "The Making of a Fly", an ordinary textbook on developmental biology was offered on Amazon Marketplace for over $ 23.7 million.[1] Two independent sellers had initially advertised this book for a commercial price, but over a period of ten days, the price continued to rise for no apparent reason, eventually reaching millions. Both sellers employed pricing algorithms to calculate selling prices automatically. The interaction of both sellers' algorithms produced a perpetual positive feedback resulting in a price spiral.

Although the textbook was not sold and its high price was (by all probability) not the result of collusion by the two sellers, this example

CONTACT Lea Bernhardt lea.bernhardt@hsu-hh.de Department of Economics, Helmut-Schmidt-University, Holstenhofweg 85, Hamburg 22043, Germany

[1] Salil K Mehra, 'Antitrust and the Robo-seller: Competition in the Time of Algorithms' [2015] 100 Minn L Rev 1323.

illustrates a possible problem caused by algorithmically set prices. In principal, the retailers could have harmed consumers by arranging some sort of coordinated behaviour, and proving their intent to do so would be difficult. In this case, the pricing algorithm could have been used as a device to facilitate collusion, which we define as *collusion by code*. This it is by no means a new type of collusion. There is, however, one major aspect which changes the impact of such arrangements: Coordinating prices can now be arranged much easier and at a much higher speed of adjustment. Changes in price-settings no longer require days or hours of deal making, but instead can be implemented in seconds. Therefore, price-fixing could become much more effective.[2]

Furthermore, allowing algorithms to collude independently of human interactions could lead to new dimensions of collusive agreements. We describe this form of anti-competitive behaviour as *collusion of code* or *algorithmic collusion*. In this case, the pricing algorithms coordinate without any kind of human intervention. This would create a completely new dimension of price fixing, leading to novel discussion about agency and accountability. We do acknowledge, however, that, as of today, it is questionable whether this poses a real threat to competition (see section 3.3).

The increasing relevance of algorithmic pricing has attracted more attention to issues arising from the application of such pricing software.[3] Some researchers, like Ezrachi and Stucke, consider algorithmic collusion very likely and therefore plead for adequate reactions such as governmental interventions.[4] They argue that pricing algorithms stabilize collusive outcomes by easing the detection of deviations from an agreement and allowing rapid price adjustments. Consequently, collusion could become more persistent. On the contrary, other authors, like Petit, heavily criticize this concept.[5] According to this view, the strict underlying assumptions do not prove to be applicable to most markets. Therefore, collusive outcomes are relatively unlikely to occur.

To determine the actual threat to competition posed by algorithms, an analysis of the functioning and practical application of pricing software, as

[2]Margrethe Vestager, 'Algorithms and Competition' (2017) <https://ec.europa.eu/commission/commissioners/2014-2019/vestager/announcements/bundeskartellamt-18th-conference-competition-berlin-16-march-2017_en> accessed 4 October 2019.

[3]OECD – Directorate for Financial and Enterprise Affairs, 'Algorithms and Collusion – Background Paper Prepared by the Secretariat' (2017) <https://one.oecd.org/document/DAF/COMP/en/pdf> accessed 7 October 2019.

[4]Ariel Ezrachi and Maurice E Stucke, 'Virtual Competition' [2016] 7(9) Journal of European Competition Law & Practice 585.

[5]Nicolas Petit, 'Antitrust and Artificial Intelligence: A Research Agenda' [2017] 8(6) Journal of European Competition Law & Practice 361.

well as the likelihood that collusion will occur, is required. Therefore, the two types of collusion involving pricing algorithms that have been proposed will be discussed in the following: collusion facilitated by the use of pricing algorithms (collusion by code) and algorithmic collusion (collusion of code).[6] This paper will initially review the literature on algorithmic collusion and then emphasize the conditions for and consequences of algorithms as a facilitating device. Additionally, we will highlight different approaches regarding detection and prosecution. The principal focus lies on the critical assessment of potential countermeasures to be implemented by regulators or other competition authorities.

Overall, we agree that several conditions impede a lasting prevalence of algorithmic collusion but competition authorities require sophisticated and state-of-the-art technology to prevent collusive outcomes. Moreover, competent authorities heavily depend on well-trained staff with statistical and programming skills. Therefore, we advocate the provisioning of more resources for competition authorities. As stated by Gal, the anti-competitive concerns arising from such scenarios are too important to ignore until detailed findings have been obtained.[7]

The paper is now organized as follows: In the following section, the basic functioning and relevant application of pricing algorithms is explained. Then, conditions for algorithmic collusion to emerge are explored and the likelihood for an actual occurrence is assessed. Subsequently, algorithms as a device for collusion are discussed in different scenarios. In the fifth section, possible countermeasures to prevent anti-competitive behaviour triggered by pricing algorithms are discussed. The last section concludes.

2. Pricing algorithms

2.1. Functioning

In general, pricing algorithms are sequences of programme codes which are intended to solve a specific problem and are based on given target determinations, such as profit maximization.[8] For this, large amounts of data are often evaluated to adjust and optimize prices. The input data

[6]Ulrich Schwalbe, 'Algorithms, Machine Learning, and Collusion' [2018] SSRN Journal <https://ssrn.com/abstract=3232631> accessed 8 October 2019.
[7]Michal S Gal, 'Algorithms as Illegal Agreements' [2019] 34 Berkeley Tech LJ 67.
[8]German Monopolies Commission, 'Algorithms and Collusion: Excerpt from Chapter I of the XXII. Biennial Report of the Monopolies Commission ("Competition 2018") in accordance with Section 44 Paragraph 1 Sentence 1 of the German Act against Restraints of Competition' (2018).

are both in-house information such as stock levels and advertising expenditure, as well as market data, such as the number of competitors, competitors' prices and sales channels. Thus, the optimal price strategies for the respective company are determined step by step as output. If, for example, a price increase of the competitors is determined, then the price-setting algorithm can adjust its own price, depending on the destination, to the price of the competitors or undercut it specifically.

The functioning of algorithms is largely determined by their design and the available data. For static algorithms, the created sequence is tracked unchanged, while dynamic algorithms can vary both the instruction sequence and the destination. Dynamic algorithms learn with the data provided to them the best possible strategies and develop them further. This allows dynamic algorithms to make time-varying price adjustments. If sufficient data is made available to the algorithms, they can independently discover patterns and find price solutions without following prescribed rules. Here, a distinction is made between supervised and unsupervised learning: in supervised learning, a predetermined solution is sought as an optimization problem, while in unsupervised learning, no objective function is specified.[9] Dynamic algorithms can thus quickly adapt to new conditions and optimize the prices according to the new conditions. There is, however, a variety of different types of algorithms, depending on the overall design as well as specific modifications.

In the above-mentioned example of the biology textbook on Amazon, the pricing was based on very simple formulas which were not created as a learning code but as simple decision rules.[10] Thus, the million price came about through a combination of two independently set algorithms, which played each other as in a price spiral to this extremely high price. The first algorithm always set the price of the book to the simple formula 1.27059 times higher than the second book offered. However, the affected competitor had set his algorithm in such a way that as reactions his own price always reflected by 0.9983 times the price of the first book. Obviously, as the price increase is always larger than the decrease in price they can never be resolved to a positive number. Consequently, an upward price spiral is created, which theoretically would have to evolve to an infinitely high price.[11]

[9]Jürgen Schmidhuber, 'Deep Learning in Neural Networks: An Overview' [2015] 61 Neural Networks 85.
[10]Even today one can assume that the vast majority of pricing algorithms follow simple rules as in the example of the biology textbook.
[11]Mehra, 'Antitrust and the Robo-seller: Competition in the Time of Algorithms' (n 1).

With the extremely high price of the biology textbook finally discovered, this spiral could be stopped by the dealers manually setting the price at a much lower level. This example illustrates the momentum of pricing which can lead to strong price developments even with simple instruction formulas. Of course, this also applies to negative price movements if the formulas had been set accordingly.

2.2. Application

Pricing algorithms are being used much more today than they were just a few years ago due to the growing availability of information.[12] According to an EU sector survey conducted in 2017, a vast majority of online retailers use pricing software for their businesses.[13] Above all, this development is based on efficiency gains for firms which can monitor their own prices as well as prices of competitors more easily. The use of pricing algorithms on large online trading platforms, such as Amazon, has risen sharply in the last years due to several efficiency reasons for companies. On these online market places, sellers sometimes change their prices many times a day which would be extremely burdensome by hand. Therefore, tools for monitoring and quickly adjusting prices have become increasingly important. In light of being constantly outperformed by competitors, firms invest more in sophisticated pricing software. Especially for large retailers with a range of several thousand different products, automatic price adjustments are essential. Using pricing algorithms, firms can adapt their prices quickly to new development on the market and also engage in predictions about future price movements. Therefore, they optimize their pricing procedures by employing computer software. They do not need to programme the software themselves but simply purchase pricing solutions from different providers. Then, they input their firm-specific data about their own costs, distribution channels, seasonal influences or customer targets into the software. Based on these information, the data is processed by the pricing software and a pricing decision is made. This outcome depends not only on the given inputs but also on the underlying decision trees. Some firms aim at price leadership, others at a high customer basis or others on exclusivity. By processing the

[12] Avigdor Gal, 'It's a Feature, Not a Bug: On Learning Algorithms and What They Teach Us: OECD Roundtable on Algorithms and Collusion' (2017) <https://one.oecd.org/document/DAF/COMP/WD(2017)50/en/pdf> accessed 13 May 2018.

[13] European Commission, 'Report from the Commission to the Council and the European Parliament: Final Report on the E-commerce Sector Inquiry' (2017) <http://ec.europa.eu/competition/antitrust/sector_inquiry_final_report_en.pdf> accessed 31 January 2020.

individual configurations, the firm-specific data and market movements, pricing algorithms can provide optimal prices in changing and evolving markets.

There exists a variety of different pricing software on the market today. Popescu provides a comprehensive overview and explains some practical examples for multi-seller online platforms.[14] She distinguishes between simple and more complex algorithms which are able to deliver forecasting of prices. According to her, the first generation of pricing software featured rule-based algorithms which follow simple instructions to lower or raise a price. These include price ceilings or general overruling decision to also undercut competitors, no matter what. The second-generation of pricing software appears to be more complex. As Popescu states, these algorithms do not follow pre-set rules but adapt to new conditions. In consequence, rules may change depending on new market developments and strategies can vary across time for one seller. In this paper, we focus on these types of more sophisticated algorithms.

In addition to the mentioned online platforms, there are also opportunities for price-setting algorithms in traditional markets. Since these algorithms basically consist of step-by-step command sequences, retailers in physical stores also use price-setting algorithms. However, this is more complicated, since the data collection is manually much more time-consuming and error-prone. Therefore, installing systems for automated price-settings are becoming more relevant. In the UK, for example, the Tesco supermarket chain pioneered the collection and analysis of real-time customer activity data.[15] Especially for sellers of perishable food, an accurate and forward-looking planning of demand is important. On the one hand, less product waste can occur and on the other hand, inventories can be optimized. In the Netherlands, too, the supermarket chain Heijn has begun to adapt prices and discounts through artificial intelligence.[16] Indicators of a change in prices include, for example, data about the current weather as well as weather forecasts, the best before date of the goods, stock levels or special offers from competitors. A weather forecast for warm, sunny weather could increase the price of

[14]Dana Popescu, 'Repricing Algorithms in E-Commerce' [2015] SSRN Journal <https://ssrn.com/abstract=2669997> accessed 7 October 2019.

[15]Bernhard Marr, 'Big Data at Tesco: Real Time Analytics at the UK Grocery Retail Giant' *Forbes* (17 November 2016) <www.forbes.com/sites/bernardmarr/2016/11/17/big-data-at-tesco-real-time-analytics-at-the-uk-grocery-retail-giant/#20ad100d61cf> accessed 7 October 2019.

[16]Silva Silva, 'Albert Heijn is Using Artificial Intelligence to Combat Food Waste' *Dutch Review* (24 May 2019) <https://dutchreview.com/news/innovation/albert-heijn-is-using-artificial-intelligence-to-combat-food-waste/> accessed 7 October 2019.

ice cream products in the next few days, whereas a special offer made by a competitor for certain types of beverage would lower the price. All these price adjustments are therefore based on pricing software, which leads to efficiency gains for dealers and should not affect consumers detrimentally. As explored in the next section, pricing algorithms could yet potentially lead to anti-competitive behaviour when they are used for price fixing and therefore contribute to welfare losses. The crucial questions are: In which cases are pricing algorithms able to collude independently and how likely is such a scenario? On the other hand, under which conditions are pricing algorithms simply used for pre-determined price-fixing? In the following sections, we will explain the features of the two types of anti-competitive behaviour in detail.

3. Algorithmic collusion

Price-setting algorithms are suspected of contributing to anticompetitive behaviour and collusive pricing under certain conditions. Firstly, the general idea of algorithmic collusion is explained and opposing views are presented. Then, we discuss conditions for algorithmic collusion and its likelihood. Based on these analyses, we argue in favour of a pragmatic approach towards algorithmic collusion in our evaluation. In practice, it can prove difficult to establish whether prices created by algorithms were set up in an illegitimate manner. Often, market observations for prices are used for benchmarking purposes. When prices are set by algorithms, it is especially difficult to establish counterfactual situations to test for collusive prices.[17] This would involve an analysis of the price-setting absent of the use of pricing algorithms for comparison.

3.1. Concept

Algorithmic collusion refers to the idea that pricing algorithms could autonomously realize tacit collusion. It implies the ability of pricing algorithms to form an agreement without human intervention. This could be done by increasing the speed for coordinating prices and enlarging the market scope for anti-competitive prices.[18] In practice, independently operating sellers would have to employ compatible algorithms to set

[17]Ariel Ezrachi and Maurice E Stucke, 'Algorithmic Collusion: Problems and Counter-measures' [2017] Submitted as background material at the Roundtable on Algorithms and Collusion at the OECD Competition Committee.
[18]Marcelo Corrales, Mark Fenwick and Nikolaus Forgó, *Robotics, AI and the Future of Law* (Springer 2018).

their prices with similar underlying strategies. By coordinating their price-setting, they can jointly maximize their profits without an explicit agreement to do so. Instead, advanced algorithms are able to decrypt one another and therefore predict intentions to change prices of competitors.[19] From a legal point of view, conscious parallel behaviour is not an infringement of Article 101 TFEU.[20] But contrary to simply observing and reacting to competitors' price-setting, these advanced algorithms could theoretically coordinate themselves, leading to concerted practices of two competitors. An actual occurrence of such an incident highly depends on the individual designs of the pricing algorithms and the market environments they operate in. In order to establish algorithmic collusion, several conditions have to be fulfilled, for example, a way of exchanging information between algorithms that could serve as a mean of communication. Intentions about future pricings and strategies need to be exchanged. We will focus on these conditions and questions of accountability in more detail in the next sections.

3.2. Accountability

When the parallel use of compatible pricing algorithms potentially results in collusion, it remains unclear which party is to be held accountable for any harm caused. Especially for more advanced algorithms, the traditional view of the user as the principal and the algorithms as an agent, acting on behalf of their principal, becomes blurred.[21] In cases where algorithms set prices autonomously, at least to some extent, determining liability seems more difficult. A joint study of the Autorité de la concurrence (ADLC) and the Bundeskartellamt (BKartA) summarizes different approaches of identifying whether the developer or the user of the algorithm should be held accountable.[22] As they show, proposals range from releasing developers from all liability to treating the algorithm as an undertaking's employee which is to be held accountable completely. The US Public Policy Council of the Association for Computing Machinery (USACM) defines a set of principles for accountability and transparency of

[19]Schwalbe (n 6).

[20]Consolidated version of the Treaty on the Functioning of the European Union – Part Three: Union Policies and Internal Actions – Title VII: Common Rules on Competition, Taxation and Approximation of Laws – Chapter 1: Rules on competition – Section 1: Rules applying to undertakings – Article 101 (ex Article 81 TEC) 5 September 2008

[21]OECD – Directorate for Financial and Enterprise Affairs (n 3).

[22]Autorité de la Concurrence and Bundeskartellamt, 'Algorithms and Competition' (6 November 2019) <www.bundeskartellamt.de/SharedDocs/Publikation/EN/Berichte/Algorithms_and_Competition_Working-Paper.html> accessed 23 January 2020.

algorithms.[23] In their statement, they explicitly declare every user of the algorithm to be held accountable, even in cases when the resulting decisions are not entirely traceable. The OECD refers to the EU's General Data Protection Regulation (GDPR) in order to address the question of accountability as the decision of algorithms have to be explainable.[24] According to their note, designers of algorithms are responsible for providing adequate information about the underlying logical processes. In order to better understand the difficulty of establishing a precise concept of algorithmic collusion, we will now turn to the discussions about it in the literature.

3.3. Opposing views

The question whether algorithmic collusion is actually likely is a controversial issue. On the one hand, authors like Ezrachi and Stucke consider such a scenario as realistic and plead for adequate reactions such as governmental interventions.[25] Otherwise, as they state, collusion may become more durable and complex. In that sense, tacit collusion can be fostered as prices are transparent to all market participants and changes in prices can be followed quickly. They express their concerns that new market dynamics, caused, inter alia, by automated price-settings, will disrupt competition. In their scenarios, consumers are being exploited by data-driven companies which not only control the trading platforms, but also misuse personal data in a detrimental way for buyers.

Others, like Petit, refer to algorithmic collusion as "science fiction".[26] It is argued that the entire concept of algorithmic collusion is based on rather strict underlying assumptions, like homogenous products or similar algorithms. In reality, as discussed in the next section, these assumptions are often not applicable to most markets. As a consequence, collusive outcomes are relatively rare to occur. According to Schwalbe, no incidents of algorithmic collusion have been reported so far.[27] Moreover, the author states that a collusive outcome could be formed completely unintentionally. In the case where two sellers independently use a similar algorithm as well as similar input data, they might end up with collusive pricing. One example of this

[23]USACM, 'Statement on Algorithmic Transparency and Accountability' (12 January 2017) <www.acm.org/binaries/content/assets/public-policy/2017_usacm_statement_algorithms.pdf> accessed 27 January 2020.
[24]OECD – Directorate for Financial and Enterprise Affairs (n 3).
[25]Ezrachi and Stucke, 'Virtual Competition' (n 4).
[26]Petit (n 5).
[27]Schwalbe (n 6).

is the case of the textbook on biology from the introduction. While the sellers never intended on reaching inflated prices, their algorithms reacted to one another in an excessive way. As Schwalbe points out, tacit collusion created by algorithms is not an infringement of competition law itself. Likewise, Mehra points to the theoretical nature of this concept.[28] Even though he also emphasizes the importance of increased research into the abilities of pricing algorithms, he encourages a cautious approach in antitrust prosecution. Moreover, he endorses evidenced-based policy interventions and regards the occurrence of enhanced tacit collusion by algorithms as an unrealistic scenario at this point in time. Additionally, Ballard and Naik point to the lack of reported cases of algorithmic collusion.[29] They state that none of the theoretical allegations against algorithmically set prices could have been proven. Furthermore, supracompetitive effects would be short-lived and unstable. It is argued that antitrust enforcers would likely face problems when determining whether the allegedly unlawful pricing is based on parallel conduct or interdependence.

A balanced approach is taken by Deng who reviews the antitrust and artificial intelligence literature in a research study.[30] His focus is on empirical support for the alleged threats posed by pricing algorithms. Deng mainly refers to an article by Crandall et al., in which the abilities of algorithms to cooperate with each other are investigated.[31] Their results show that cooperation between two machines in a repeated stochastic game can occur. But as this study is based on simplified environments, Deng concludes that the results cannot easily be transferred to the real world. In summary, he favours a cautious and proactive approach in order to face further developments.

Our own assessment on the likelihood of algorithmic collusion and its implications also stems from a pragmatic approach, as we elaborate in the next section.

3.4. Evaluation

Pricing algorithms may induce collusive outcomes under certain circumstances. In addition to the individual design of the algorithms, some structural market conditions for algorithmic collusion are required.

[28]Salil K Mehra, 'Robo-seller Prosecutions and Antitrust's Error-cost Framework' [2017] CPI Antitrust Chronicle 36.

[29]Dylan I Ballard and Amar S Naik, 'Algorithms, Artificial Intelligence, and Joint Conduct' [2017] CPI Antitrust Chronicle 29.

[30]Ai Deng, 'When Machines Learn to Collude: Lessons from a Recent Research Study on Artificial Intelligence' [2017] <https://ssrn.com/abstract=3029662> accessed 31 January 2020.

[31]Jacob W Crandall and others, 'Cooperating with Machines' [2018] 9(1) Nature Communications 233.

These include, inter alia, a high frequency of interactions, low buyer power and homogenous products. These criteria for algorithmic collusion are now assessed to draw our conclusion.

3.4.1. Design of the algorithms

If several companies use similar or mutually compatible pricing algorithms, coordination is more likely to occur. This is particularly the case when parts of the decision trees of the algorithms feature similar patterns. The outcome of the pricing decision is then based on the same executed steps, resulting in aligned prices, given matching inputs. For example, if two companies use the same software programmed by one provider and insert the same input data, such as the number of competitors in the market or the frequency of price changes, then the same prices should appear. Algorithmic collusion is thus facilitated. Also, the ability of algorithms to communicate with each other is of central importance. In this context, communication refers to an exchange between market participants about their prices and quantities as well as the possibility to provide feedback to other parties.[32] By exchanging such information, firms can coordinate future output and prices. This, in turn, forms the basis for future coordination. In an extreme case, algorithms could even "decode" one another and therefore predict future outcomes.[33] Going beyond a mere observation of competitors' prices, these advanced algorithms might also make predictions about other market participants' moves and adapt their own price-setting accordingly. Algorithms with the capabilities of developing their own pricing strategies, adapting to new competitors and changing environments, could possibly optimize their price-setting via signalling.[34] These self-learning algorithms might signal pricing intentions to test certain price levels and align their behaviour in a novel way. Moreover, since the information is not exchanged explicitly, signalling facilitates collusive outcomes and reduces the cost of coordination significantly.[35] More details on signalling practices can be found in section 5.3.2.

Direct communication between algorithms, however, is seen as one form of explicit collusion. In the economics literature, as shown by

[32] Christoph Engel, 'Tacit Collusion: The Neglected Experimental Evidence' [2015] 12(3) Journal of Empirical Legal Studies 537.
[33] Schwalbe (n 6).
[34] Autorité de la Concurrence and Bundeskartellamt, 'Competition Law and Data: Joint Working Paper' (2016) <www.bundeskartellamt.de/SharedDocs/Publikation/DE/Berichte/Big%20Data%20Papier.pdf?__blob=publicationFile&v=2> accessed 31 January 2020.
[35] OECD – Directorate for Financial and Enterprise Affairs (n 3).

Schwalbe, there are several studies exploring the relationship between communication and the possibility of collusion.[36] For example, Engel shows that the ability of exchanging information about intended prices increases the likelihood of collusion significantly.[37] Even further, Engel states that guarantees to match competitors' prices also benefit collusive outcomes. Similarly, Harrington et al. analyse the modes of communication which lead to collusion.[38] They distinguish between price announcements which are non-binding on the one hand and written information exchanges which are unrestricted on the other hand. Their results show that the first kind of communication leads to collusive outcomes only for symmetric firms in a duopoly, whereas the latter form of communication even results in collusion for non-symmetric firms. However, these findings are sensitive to certain market factors like the number of competitors which will be discusses in more detail in the next section. As Fonseca and Normann explain, the effect of communication on collusive results is non-monotonic in the number of firms.[39] In markets with a large amount of competitors, collusion disappears even when firms are able to communicate. In markets with a couple of firms, collusive outcomes strongly depend on the possibility of communication. Therefore, the number of competitors is crucial in determining the likelihood of collusion with or without communication.

3.4.2. Market conditions

Additionally, a high degree of market transparency may benefit collusion.[40] As Ivaldi et al. explain, the provisioning of data about competitors' prices in real-time facilitates the stability of a cartel agreement. Therefore, collusive behaviour can be stabilized by greater price transparency. According to Ivaldi et al, quick retaliations in reaction to deviations from the agreement are more likely in more transparent markets. On the other hand, increasing price transparency also benefits consumers as they are better informed about alternative products and prices. With that in mind, transparency is an ambiguous factor when it comes to collusive outcomes. Thus, transparency influences market outcomes

[36] Schwalbe (n 6).
[37] Engel (n 32).
[38] Joseph E Harrington Jr, Roberto H Gonzalez and Praveen Kujal, 'The Relative Efficacy of Price Announcements and Express Communication for Collusion: Experimental Findings' [2016] 128 Journal of Economic Behavior & Organization 251.
[39] Miguel A Fonseca and Hans-Theo Normann, 'Explicit vs. Tacit Collusion – The Impact of Communication in Oligopoly Experiments' [2012] 56(8) European Economic Review 1759.
[40] Marc Ivaldi and Others, 'The Economics of Tacit Collusion' [2003] Final Report for DG competition, European Commission 4.

substantially but the result may not always be collusive. The German Monopolies Commission argues that algorithms can also contribute to a higher degree of transparency by analysing large amounts of data in a short time.[41] Therefore, a greater availability of data and a more powerful application of computer programmes to analyse the data reduce opaqueness and increase predictability of price-setting firms. Strategic pricing decisions are then facilitated.

Besides transparency, the number of competitors in one market determines the likelihood of collusive outcomes. As Horstmann et al. show, the degree of collusion decreases with the number of competitors.[42] That is, there is a higher likelihood for tacit collusion on markets with only two firms. The authors demonstrate that a linear number effect can be observed with regard to the possibility of coordination. In reality, the number of competitors is usually not restricted to only a few firms. In our view, this impedes the occurrence and prevalence of algorithmic collusion. This is also in line with a study by Potters and Suetens.[43] They show in a review of experimental studies that tacit collusion depends heavily on the number of competitors. The authors find that coordination of prices is highly unlikely when passing a threshold of four sellers in a market. In our view, this impedes algorithmic collusion to a large extent in the real world as we mostly face markets with a large number of sellers.

Furthermore, low buyer power and homogenous products benefit collusive outcomes.[44] For example, in a market with a large number of consumers but only a small quantity of suppliers, consumer power is limited. Additionally, when goods are homogenous and consumers cannot easily observe differences in quality, firms can take advantage of these situations and agree on price fixing. Moreover, in markets with no innovations, mergers, market entries or exits, the scope for collusive outcomes tends to be smaller. All of these conditions and more detailed explanations can, inter alia, be found in papers by the OECD,[45] the German Monopolies Commission,[46] or the UK's Competition and Markets Authority CMA.[47] In addition,

[41]German Monopolies Commission (n 8).

[42]Niklas Horstmann, Jan Krämer and Daniel Schnurr, 'Number Effects and Tacit Collusion in Experimental Oligopolies' [2018] 66(3) The Journal of Industrial Economics 650.

[43]Jan Potters and Sigrid Suetens, 'Oligopoly Experiments in the Current Millennium' [2013] 27(3) Journal of Economic Surveys 439.

[44]Schwalbe (n 6).

[45]OECD – Directorate for Financial and Enterprise Affairs (n 3).

[46]German Monopolies Commission (n 8).

[47]Competition and Markets Authority, 'Pricing Algorithms: Economic Working Paper on the Use of Algorithms to Facilitate Collusion and Personalised Pricing' [2018] <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/746353/Algorithms_econ_report.pdf>.

Schwalbe provides a comprehensive overview of the findings on algorithmic coordination in the literature on game theory and data science.[48] He also concludes that collusive outcomes are highly complex and unlikely to be achieved.

We consider the large amount of sellers on online marketplaces as one reason for relatively rare collusive outcomes. Also, the number of competitors is not stable over time. As firms enter or exit the market, the coordination of prices becomes more difficult. In reality, we frequently observe market entries, exits and mergers. These unstable market conditions impede the occurrence of algorithmic collusion. Also, we regard the assumption of homogenous products as not applicable to most markets. Based on these findings, we regard collusive outcomes theoretically possible but likely to fail in practice as they are not stable over time. In particular, number effects and changing market conditions are impeding algorithmic collusion. As a consequence, we assess algorithmic collusion as very unlikely at this point in time.

3.4.3. Conclusion

We identified the large amount of competitors, changing market conditions due to entries or exits of firms, and mostly heterogeneous products as factors which prevent algorithmic collusion. Additionally, pricing algorithms are required to exchange information with each other in order to coordinate prices. As the ability of algorithms to communicate is still limited, we argue that collusive outcomes are relatively unlikely to occur. Moreover, the chances of two firms deploying compatible pricing algorithms which are able to read each other and are also given the same input data are rather low.

All in all, given changing market conditions and constantly evolving pricing algorithms with different set-ups and designs, collusive outcomes seem unobtainable in the vast majority of cases. Therefore, algorithmic collusion is very unlikely at this point in time. There are, however, different cases of collusive outcomes with algorithms involved. When sellers use algorithms as tools to establish and maintain a cartel, algorithms serve as facilitating devices for collusion. This form of anti-competitive outcome is discussed in detail in the next section.

4. Algorithms as a facilitating device for collusion

Collusion by code refers to the deliberate application of behavioural coordination algorithms and thus to the establishment of a cartel.

[48]Schwalbe (n 6).

Although this does, of course, not initially pose a completely new problem, it is becoming more relevant than before due to the widespread application of algorithms and greater data availability.

If prices are set using algorithms, possible agreements can be (i) realized much faster and (ii) stabilized by greater price transparency. This particularly concerns the possibility of rapid price adjustments if deviations from the collusion agreement are discovered. This would make short-term deviations unprofitable, since companies can analyse data on price changes of their competitors in real time. Mutual supervision and sanctioning are thus easier to enforce among cartel members and the companies involved have less incentive to deviate from the agreement. Thus, the spread of price algorithms can basically help cartels to become more stable.

The use of algorithms as tools to perform collusion depends on the one hand on the individual structure of the algorithms and on the other on the prevailing market conditions. If several companies use similar or mutually compatible pricing algorithms, behavioural coordination can occur more frequently. In particular, if the decision rules have similarities within the order sequences, the pricing responses of the companies will go in the same direction. For example, if two companies using the same software deliberately give the same input data, such as the number of competitors in the market or the speed of response to price changes, then similar pricing decisions are the consequence. In addition to the individual design of the algorithms, a number of structural market conditions for automated collusion are required.

4.1. Scenarios

Collusion, which occurs as a result of an agreement made by humans but is executed via algorithms, can broadly be classified into three different scenarios.

4.1.1. Messenger scenario

The first case is referred to as the "messenger scenario".[49] As the name suggests, algorithms are used here to implement and monitor the collusive agreement. That is, the algorithms serve as messengers about planned price increases, supply reductions or special offers. This is valuable information in a competitive market as the pricing depends on the

[49]Ariel Ezrachi and Maurice E Stucke, 'Artificial Intelligence & Collusion: When Computers Inhibit Competition' [2017] University of Illinois Law Review 1775.

competitors' actions. In a situation where two sellers on an online market platform decide to fix their prices, they can stabilize their agreement by constantly monitoring cartel compliance. If deviations from the agreed prices are detected, the software can automatically alert other cartel members.

In order to illustrate this scenario, two practical examples concerning the Amazon Marketplace are shown. In the first case, a cartel between different sellers on Amazon US was maintained by coordination via computer algorithms. This was the first prosecution for breaches in competition law regarding online marketplace sales in the US.[50] The so-called Topkins-case, named after the founder of the online retail shop David Topkins, revealed this coordination of poster prices in late 2013.[51] The posters were sold on Amazon Marketplace at inflated prices due to an agreement with other online sellers to fix prices. The retailers used their computer algorithms to adjust their prices in coordinated actions, enabling them to react instantaneously to price fluctuations. In 2015, the US Department of Justice charged Topkins and his co-conspirators with price-fixing. The agreement was based on human coordination but was implemented by computer algorithms. In that sense, algorithms were used as messenger between firms to fix prices.

A second, quite similar case was brought before a court of law in the UK. A small toy retailer from Birmingham was found guilty of price fixing for posters and frames on Amazon's UK website. Trod Ltd had entered an agreement with another seller to maintain their prices at certain levels and implemented the cartel by using pricing software. This horizontal price-fixing cartel ended when Trod's counterpart applied for leniency at the UK's CMA. As a result, the CMA fined Trod Ltd for violating against competition law in 2016, whereas the other seller was secured immunity from fines.[52] Due to the previously discussed case in the US, the testifying company could have been incentivised to break up the cartel in order to avoid fines. In any case, the novelty of this lawsuit featured the usage of pricing algorithms to implement a humanly agreed cartel in the UK. The software itself was not specially

[50] Salil K Mehra, 'US v. Topkins: Can Price Fixing be Based on Algorithms?' [2016] 7(7) Journal of European Competition Law & Practice 470.

[51] The United States Department of Justice, Office of Public Affairs, 'Former E-Commerce Executive Charged with Price Fixing in the Antitrust Division's First Online Marketplace Prosecution' (6 April 2015) <www.justice.gov/opa/pr/former-e-commerce-executive-charged-price-fixing-antitrust-divisions-first-online-marketplace> accessed 31 January 2020.

[52] Competition and Markets Authority, 'Decision of the Competition and Markets Authority: Online Sales of Posters and Frames' (2016) <https://assets.publishing.service.gov.uk/media/57ee7c2740f0b606dc000018/case-50223-final-non-confidential-infringement-decision.pdf> accessed 31 January 2020.

designed for this anti-competitive behaviour but instead is used by many Amazon sellers to monitor and adjust their prices.[53]

4.1.2. Hub and spoke

The second scenario deals with the collusion of a third party and is, therefore, referred to as *a hub and spoke* cartel.[54] Here, the sellers use the same algorithm and a common hub to adjust their prices. In this scenario, competing firms can coordinate their behaviour via a common third party in vertical relations, for example between distributors and a common supplier.[55] The CMA considers hub and spoke arrangements as "the most immediate risk", mainly because it does not require sophisticated technology or advanced methods to align prices.[56] Instead, the spokes adopt the same algorithm which is coordinated by the hub. According to Ezrachi and Stucke, this scenario is especially prone to achieving anticompetitive outcomes, when a "cluster of similar vertical agreements" is built.[57] It therefore depends on the number of competitors in one market which use the same pricing method. Such structures are more difficult to uncover for regulators and the involved parties are less likely to be exposed.[58] This is mainly due to the complex, trilateral agreement within the operation. One crucial component in establishing this hub and spoke cartel is some sort of information flow from one party to another. The hub has to be able to get in contact with the spokes in order to coordinate the price changes. As a result, the spokes are not engaging in a risky information sharing process but instead receive information via the hub.[59]

4.1.3. Predictable agent

The third scenario encompasses the parallel use of individual algorithms, resulting in tacitly coordinating prices.[60] Ezrachi and Stucke refer to it as the *predictable agent*, where the algorithms are unilaterally implemented by each party itself. In this case, the companies involved have not

[53]Mark Tricker and Susanna Rogers, 'Antitrust Concerns Surrounding Automatic Repricing Software' *Digital Business Laywer* (October 2016) <www.nortonrosefulbright.com/-/media/files/nrf/nrfweb/imported/digital-business-lawyer-article-subr_mjjt.pdf> accessed 31 January 2020.
[54]Competition and Markets Authority, 'Pricing Algorithms' (n 47).
[55]Okeoghene Odudu, 'Indirect Information Exchange: The Constituent Elements of Hub and Spoke Collusion' [2011] 7(2) European Competition Journal 205.
[56]Competition and Markets Authority, 'Pricing Algorithms' (n 47).
[57]Ezrachi and Stucke, 'Artificial Intelligence & Collusion: When Computers Inhibit Competition' (n 49).
[58]Patrick Actis Perinetto, 'Hub-and-spoke Arrangements: Future Challenges Within Article 101 TFEU Assessment' [2019] 15(2–3) European Competition Journal 281.
[59]ibid.
[60]Ezrachi and Stucke, 'Artificial Intelligence & Collusion: When Computers Inhibit Competition' (n 49).

intentionally agreed on fixing prices but instead use their computer algorithms to follow price leadership and to detect deviations. In that way, market transparency increases for the companies, easing price predictions in order to adjust their own pricing. The firms employ their computer algorithms as part of their business plan in order to monitor the market. Moreover, they aim at detecting some kind of correlation in their actions. Algorithms can, therefore, establish a common understanding by detecting price deviations and punishing. They can calculate the likelihood of common actions and anticipate price changes. By doing this, the software enables pricing predictions which can lead to collusion. According to Ezrachi and Stucke, one condition for this scenario to prevail is a similar design of the algorithms. If the algorithms are compatible with each other, they can signal intentions and show competitors what they can expect from the pricing. The CMA views the predictable agent scenario as a long-term risk which requires technologically advanced algorithms.[61] Also, when compared to the hub and spoke scenario which only involves the employment of the same pricing algorithms, the predictable agent seems more sophisticated. As the underlying assumptions for this scenario are rather strict, the likelihood of an actual occurrence is limited. To the best of our knowledge, there has not been a case like this to date.

4.1.4. Assessment

The three mentioned scenarios have to be evaluated quite differently in our view. The messenger scenario has already occurred in reality. The hub and spoke scenario has not been observed entirely yet, but there are pricing systems which combine certain features of this scenario.[62] This suggests that these scenarios are far more likely to occur than the third one. In fact, the messenger scenario is the easiest of the three to achieve. Sellers on online platforms can easily fix their prices by communicating their intentions and pricing strategies with one another. Pricing algorithms facilitate their actions when used as devices for exchanging information. As for stability, the collusive prices can be maintained as long as no regulator, competition authority or bodies like consumer associations detect the anti-competitive behaviour. Therefore, we believe

[61] Competition and Markets Authority, 'Pricing Algorithms' (n 47).

[62] One example for a case with a similar structure and technical implementation could be the Lithuanian company called Eturas which administrates an online travel booking system. In 2012, the Competition Council of Lithuania fined Eturas (see ECLI:EU:C:2016:42 – *Eturas* (2016) Case C-74/14) for coordinating the provision of discounts between the travel agencies in its system via their common hub. Legally, this case however is not defined as a hub and spoke collusion, see *Opinion of AG Szpunar*, 'Case C-74/14, Eturas, EU:C:2015:493, §65' (2015).

that the messenger scenario is an actual threat to competition and more instances of cases like the ones described above are likely to follow. Cartel members are able to use technology in order to lower transaction costs of collusion and therefore make cartels more effective.

The hub and spoke scenario does require more sophisticated structures and concerted action of several parties. Pricing algorithms ease the coordination among cartelists and stabilize the agreement. Thus, we also consider this scenario likely but we acknowledge the greater dimensionality of such cases. Both the messenger and the hub and spoke scenarios are not completely new problems but they are now being more easily implemented and maintained through the use of pricing algorithms.

The predictable agent scenario differs from the other two scenarios as the sellers may not intentionally act unlawfully. By employing similar pricing algorithms, they could, however, reach collusive outcomes. As this scenario requires advanced technology, a stable market environment and some kind of correlation in the sellers' pricing, the predictable agent scenario seems rather unlikely in our view. As of today, we cannot report any actual occurrence of this scenario.

With regard to preventing such cases or, at least, increasing coordination costs for cartel members in the future, several remedies should be taken into consideration. Possible countermeasures are now discussed in the following chapter.

5. Remedies

In order to prevent or hamper pricing algorithms from contributing to anti-competitive behaviour, we propose several countermeasures. These include monitoring activities by competent authorities, developing software for detection and verification of excessive prices and, in some cases, legislative action. In the following section, we discuss these remedies in detail.

5.1. Monitoring

Excessively high prices can only be detected when a system for permanent price monitoring is installed. Therefore, monitoring of price fluctuations and overall market developments is essential in order to observe anomalies. Especially for the messenger and hub and spoke scenarios, extensive monitoring activities could prove beneficial. We consider monitoring particularly important in these scenarios, as the decision-making processes are still led by humans and prices usually change in observable units. For the predictable agent scenario, the scanning of market developments is equally important but the anti-competitive intentions are more difficult to prove. Since retailers have to use similar or at least highly compatible algorithms, competition authorities require not only to detect pricing anomalies, but also evidence of unlawful misconduct. Thus, monitoring is an important tool for a first indication of anti-competitive behaviour but for the predictable agent scenario, it is not sufficient. As we elaborate further, other countermeasures could also be taken into consideration.

5.1.1. Equipment

Above all, competition authorities have to be adequately equipped with powerful tools for detecting collusive prices. On the one hand, they need to be up to date with technological progress and hence require skilled staff. Expertise in statistics and information technology is essential. In order to analyse large amounts of data, to process the information collected and to conduct further investigations, the authorities rely on the knowledge and experience of their staff. In addition, well-trained staff requires modern technology and high computational power. These factors are crucial when it comes to one of the main tasks that the authorities face: monitoring price movements across a wide range of different products in various markets.

Against this background, the German Monopolies Commission recommends explicitly to closely monitor markets for price anomalies.[63] In the case of concrete allegations of collusion, an investigation could be initiated in the context of an antitrust sector inquiry. An example of a successful application of such monitoring instruments is the detection of market manipulation regarding the reference rate Libor (London Interbank Offered Rate). This standardized interbank interest rate is still widely used today, despite several attempts to reform the entire rate-setting system. The Libor serves as an indicator for the price at which banks lend money to each other, mostly unsecured funds on the London interbank market. Thus, the Libor is a benchmark interest rate for derivative financial instruments and loans with variable interest rates. The calculation of Libor is based on reports from a small group of banks in a so-called representative bank panel and is published daily. Initially, this system was administered by the British Bankers' Association,

[63] German Monopolies Commission (n 8).

a banking lobby group without regulation by any authority.[64] The banks reported the interest rates by estimating their borrowing costs, at different maturities and in different currencies, but without disclosure of the actual interest rates paid. For this reason, the banks involved could simply coordinate with other banks by altering the rates into a certain direction. In this way, interest rates were kept artificially low to reduce refinancing costs and to strengthen traders' positions. As stated by Schrimpf and Susko, arrangements were made between trading desks of the panel banks to favour derivative positions with manipulated interest rates. Investigations into the rates only started when regulators used monitoring software to trace back interest rates. They were informed about indications for possible collusions due to flagged interest rate movements which occurred after 2007. Noticeably low interest rates were reported, despite the tensions on the unsecured interbank money market, leading to targeted screenings for market manipulation and collusion in the US and Europe.[65] As a result, the European Commission imposed fines on eight banks for cartel offenses and set up a working group of the FSB (Financial Stability Board) to develop alternative reference rates. This example of the Libor manipulation demonstrates how the employment of price monitoring and verification software can support the work of competition and regulation authorities. Therefore, we believe that automated screenings can facilitate the detection of market rigging and coordinated behaviour of market participants.

5.1.2. Algorithms as compliance tools

Along with the application of pricing software for detecting price anomalies in the past, there is also the possibility of monitoring price-setting in real time. Such automatic monitoring systems can be used as compliance tools to identify so-called *plus factors*.[66] These include, for example, unexplained price increases which vary significantly from historical prices for a specific product. That is, all influential factors such as supply shortages or new taxation laws taken into account, a price shift can be observed for no apparent reason, or output restrictions at one company can occur, despite high demand overall. Also, stable market shares and low customer churn, combined with rising prices, are

[64]Andreas Schrimpf and Vladyslav Sushko, 'Beyond LIBOR: A Primer on the New Benchmark Rates' [2019] BIS Quarterly Review March.
[65]Rosa M Abrantes-Metz and Albert D Metz, 'The Future of Cartel Deterrence and Detection' [2019] CPI Antitrust Chronicle, January.
[66]William E Kovacic and others, 'Plus Factors and Agreement in Antitrust Law' [2011] 110 Mich L Rev 393.

one of these plus factors, as described by Kovacic et al. In these situations, algorithms can be used to constantly recalculate and compare prices. In the case of significant deviations from past ratios or benchmark values from competitors in the industry, an alert can be installed. Regulators can then be informed about changes in pricing patterns when they actually happen. This kind of real-time monitoring system could be a powerful tool for authorities, but requires a lot of information and facilities to analyse the data. Historical prices for the purpose of comparison have to be collected, thresholds for excess prices need to be defined and seasonal influences and industry-specific characteristics have to be taken into consideration. In practice, these requirements would impede most regulatory bodies from installing permanent monitoring systems due to the limited equipment available. We therefore deem these possibilities as not applicable for most institutions today. But we are convinced that more sophisticated developments in the way algorithms are designed are necessary and will likely appear more frequently in the future. Cases like in the messenger scenario could be revealed with the use of compliance tools based on algorithms. For example, two sellers could be convicted of fixing prices by using algorithms as a means of communication with the help of an automated monitoring system that embodies the mentioned plus factors. Thus, we plead for further research into algorithms as compliance tools.

5.2. Development

Besides closely monitoring price developments and checking for possible anti-competitive outcomes, there is also the possibility of developing devices for authorities to take further action. With regards to the mentioned scenarios, the predictable agent, in particular, requires more sophisticated countermeasures. A possible solution would be the development of algorithms to disrupt collusive outcomes, as well as an increase in providing algorithms for consumers to counterbalance the technological advances of price-setting firms and a stronger focus on transparent algorithms. The latter helps to promote traceable pricing decisions and could prevent companies from unintentionally engaging in anti-competitive behaviour, as in the predictable agent scenario.

5.2.1. Disruptive algorithms

Once collusive prices have been detected, regulators could either initiate prosecutions or, even further, could try to destabilize the cartel. For this, advanced techniques are required. For example, disruptive algorithms could be set up by regulators which are able to disturb collusive equilibria. Especially in markets with a low number of market participants, such tools can be used to send out and test price signals. If collusive equilibria are found, undercutting the price could lead to some deviational effects. In May 2018, the European Commissioner for Competition, Margarethe Vestager, announced an investigation into the development of such disruptive algorithms. According to Vestager, regulators need to "upgrade their antitrust toolbox".[67]

This approach, however, demands high technological efforts (and therefore costs) and poses the risk of contributing to possible market distortions or inefficiencies. Using algorithms to artificially influence market prices has a deep impact on the pricing of companies. Such measures are in principle nothing more than regulations of maximum prices and thus represent a much stronger intervention than competition policy measures. They should, therefore, be taken with caution.

5.2.2. Algorithmic consumers

Additionally, developing algorithms for consumers, so-called *algorithmic consumers*, is suggested.[68] These algorithms support consumers already by outsourcing decisions in their daily lives. According to Gal and Elkin-Goren, the widespread use of platforms for price comparison and price prediction is one of the advantages consumers gain when using algorithms. In that way, they also reduce transaction costs and decrease time spent searching for and comparing alternative products. Moreover, algorithms are even more powerful when implemented in order to counterbalance the price-setting software of firms. This, in theory, could even make collusion more difficult. Put differently, they can increase competition by providing consumers with some sort of advantage in knowing about price differences. This allows ordinary customers to make well-informed decisions. In comparison with decisions made on a purely human level, algorithmic consumers benefit from the ability to collect, store and process data much faster and more efficiently. Therefore, these types of algorithms increase consumers' market power and could prevent harm done by collusive prices. In practice, however, the development of algorithmic consumers requires a large amount of available data. As

[67]Foo Y Chee, 'EU Considers Using Algorithms to Detect Anti-competitive Acts' *Reuters* <www.reuters.com/article/us-eu-antitrust-algorithm/eu-considers-using-algorithms-to-detect-anti-competitive-acts-idUSKBN1I5198> accessed 31 January 2020.
[68]Michal S Gal and Niva Elkin-Koren, 'Algorithmic Consumers' [2016] 30 Harv JL & Tech 309.

companies usually have an informational and technological advantage, such market solutions are rather difficult to implement.

On the upside, algorithmic consumers challenge algorithmic coordination not by means of regulation but by enhancing consumers' market power with the same kind of tools that are used against them. Therefore, we are convinced that research into the design and architecture of pricing algorithms will eventually also pay off for consumers. In case that collusion by code becomes a serious problem, respective algorithms could be part of a solution endogenously provided by the market.

5.2.3. White-box algorithms

In this context, we presume that it is also worthwhile to put more emphasis on so-called *white-box algorithms*.[69] These algorithms are designed as transparent and clear code blocks, in contrast to *black-box algorithms* which are very much impenetrable. The white-box algorithms are almost completely visible and understandable to humans with suitable knowledge and equipment. Therefore, one can retrace steps leading to a certain price decision. They reveal the structure and design of the algorithms but are still executable, contrary to pseudo-codes (discussed in section 5.3.1). With certain inputs and available technology, pricing can be replicated by stringing individual building blocks of the algorithms together in order to create a full sequence of code. On open source platforms such as Rapid Miner, smaller white-box algorithms can be simulated and tested for training purposes.[70] Whether white-box algorithms should be used more frequently in practice than their more secretive black-box counterparts seems debatable. On the one hand, opaque and indecipherable software protects business' plans and allows for innovative pricing schemes. On the other hand, it is argued that many companies desire understandable pricing software as they demand greater market insights.[71] This returns more accurate price predictions and allows companies to set their business plans accordingly. It is, however, questionable if algorithms are (or should be) designed such that humans, i.e. competitions authorities, can easily understand their logic. Stipulating white-box algorithms would, similar to the application of disruptive algorithms, be a deep intervention into the market process. Such a regulatory interference would most likely have a strong negative

[69]Boris Delibašić and others, 'White-Box or Black-Box Decision Tree Algorithms: Which to Use in Education?' [2012] 56(3) IEEE Trans Educ 287.
[70]RapidMiner, 'RapidMiner Pricing' <https://rapidminer.com/pricing/> accessed 31 January 2020.
[71]Francisco Beneke and Mark-Oliver Mackenrodt, 'Artificial Intelligence and Collusion' [2019] 50(1) IIC 109.

effect on innovations. Therefore, we argue in favour of a cautious approach in order not to disrupt technological progress and scare off investors. On the contrary, we deem a greater focus on white-box algorithms as helpful for regulators only under certain circumstances which would allow officials to gain insights into pricing decisions. Business secrets need to be taken into account as well as incentives for developing new pricing algorithms.

In conclusion, pricing algorithms can be designed in a way that enhances transparency and allows traceable decisions. In theory, they could eventually even disrupt collusive equilibria and strengthen consumers' market power. As technological progress evolves, we believe that more possibilities for consumers and regulators may arise. This could prove especially advantageous when dealing with opaque pricing decision as described in the messenger or hub and spoke scenario. In these cases, collusive prices are maintained due to obscure price-settings which are not entirely revealed to consumers or regulators. Greater transparency therefore benefits fair competition but we strongly believe that regulations need to be designed in a way that does not adversely affect technological progress and entrepreneurial freedom.

5.3. Legislative action

Apart from solid monitoring processes and software development, one could also consider legislative action against algorithmically facilitated collusion. In general, we do not call for immediate legislative action as we do not see collusion by code as an entirely new problem. On the contrary, we consider this kind of anti-competitive behaviour to be covered mainly by existing laws. There are, however, certain proposals to improve ways of preventing algorithmic collusion and to ease prosecution (*compliance by design*).[72] This section discusses transparency requirements, speed limitations for price changes and trading activities as well as a reversal of the burden of proof.

Before analysing these ideas, two important aspects from a legal point of view have to be noted. Firstly, any kind of explicit collusion through algorithms must not be treated differently from human made collusion.[73] As this refers to an agreement made by humans which is only executed by algorithms, this is valid for cases when algorithms are used as devices to apply collusive prices. For algorithmic collusion, tacit agreements are

[72]Vestager (n 2).
[73]Schwalbe (n 6).

more relevant. So, secondly, today's antitrust laws prohibit explicit but not implicit coordination.[74] A purely tacit understanding of firms in an industry to not compete against one another is therefore not illegal per se. This is important when companies use the same pricing software without knowing about it, leading to a situation where both algorithms could theoretically set prices in the same direction. As a result, the pricing of two companies could – completely unintentionally – appear to be anti-competitive. Thus, any occurring cases of collusion using algorithms should be covered by the current competition law. In consequence, amendments or reforms of the prevailing antitrust laws seem to be unnecessary at the moment. We do recommend, however, that current competition law be adapted once autonomous algorithms become greater concerns in the future. Today, most forms of stricter regulation in this regard impose certain risks of cutting off innovation. For instance, a complete ban of specific classes of algorithms which could facilitate collusion, would have deterrent effects on innovation. This contrasts the proposal made by Harrington.[75] He suggests to prohibit the application of algorithms with certain characteristics that enable firms to set prices above the competitive equilibrium price. In order to elaborate which features are prone to an investigation, the author suggests to carry out market simulations by competent authorities. In our view, however, such a procedure requires not only a lot more resources for regulators but also seems practically impossible to enforce. Furthermore, such a policy would require a continuous adaptation to the latest technology. New algorithms would have always to be checked for their probability of collusion. Therefore, a ban of certain pricing algorithms may not be desirable.

5.3.1. Transparency

In this regard, different approaches should be considered in our view. A comprehensive transparency obligation for developers and operators of the algorithms could provide more understandable pricing. In particular, we think that the disclosure of the design of the algorithm and related decisions should be considered. For example, this would make rankings of individual price decisions more understandable. Also, pseudo-codes or simulation studies could be published in order to provide traceable pricing decisions. Such pseudo-codes do not follow a specific syntax

[74]Thomas Weck, '2nd CoRe Conference Proceedings: Current Issues of Competition Policy in E-Commerce' [2019] 3(1) European Competition and Regulatory Law Review 9.

[75]Joseph E Harrington Jr, 'Developing Competition Law for Collusion by Autonomous Price-setting Agents' [2017] *SSRN Journal*. DOI: 10.2139/ssrn.3037818.

and are not a proper programming language. They are readable by humans, go through each step in a sequence of instructions and can, therefore, serve as a guide to understanding the end result. Graphically, they can also be interpreted and understood as decision trees. In addition, simulation studies could be run as a verification tool. With pre-defined inputs about firm-specific data, the pricing algorithms can be tested. This requires high standards of technical equipment plus sufficient knowledge about the interpretation of the results. In this context, an obligation on the part of the verifying authorities for distributors to provide a description of their algorithm could be helpful. This would facilitate the traceability of the pricing. In order not to disclose business secrets and not to diminish the innovative strength of companies, it would also be conceivable to oblige companies not only to disclose their price data directly, but at least to document it in such a way that it could be used for price analysis on demand.[76] As discussed previously (see section 5.2.3), we therefore advocate greater emphasis on transparency on the one hand, but we also see certain risks regarding obligations for firms on the other hand. In practice, developers of pricing algorithms which are too complex to fully replicate should not be undermined by strict legislation. We argue that greater transparency obligations should not suppress innovation and further research into the development of powerful pricing algorithms.

5.3.2. Speed

Another crucial factor in establishing and maintaining a collusive agreement is the speed at which prices can be changed. According to the UK's CMA, algorithms can enhance the stability of an agreement by allowing cartel members to detect deviations from the agreed prices faster.[77] If deviating prices are recognized by the computer programme, other cartel members can react accordingly and respond with some sort of punishment. This is vital in order to keep the cartel stable. Deviating from the agreement may prove beneficial to one party in the short term but will most likely end the cartel in the long run. Also, by outsourcing the adherence to the agreement from controlling the prices manually, algorithms may reduce accidental deviations. As the CMA states, human errors are therefore somewhat erased. In light of this, speed plays a major role. If prices are set using algorithms, possible agreements

[76]Uwe Salaschek and Mariya Serafimova, 'Preissetzungsalgorithmen im Lichte von Art. 101 AEUV' [2018] 68 (1) WUW: Wirtschaft und wettbewerb= Concurrence et marché= Competition and trade regulation 8.
[77]Competition and Markets Authority, 'Pricing Algorithms' (n 47).

can be made faster and deviations are detected more quickly.[78] Mutual surveillance of cartel members is thus organized more efficiently. Also, a higher frequency of interactions enables firms to reprice their products more often.[79] More frequent prices changes can, therefore, facilitate retaliation for deviating prices from an agreement.

In the past, traders at physical stock markets adjusted their prices manually. They had to observe their competitors' price changes and adjusted their own prices accordingly. Today, almost all stocks are traded on electronic trading platforms. Traders use algorithmic pricing to follow market trends while the increased speed at which decisions are now made has changed market communication completely. Traders can employ algorithms in order to anticipate price changes by signalling information about planned transactions to competitors. Algorithms can, therefore, be used as a device for collusion by sending a signal into the market. Depending on the subsequent reaction, traders can adapt their pricing accordingly. This could lead to a situation where one market participant is establishing a cartel by sending signals about a desired price increase to its counterparts. If they decide to follow the agreement, they quietly adjust their prices accordingly. This could happen in a few seconds, without being noticed by other market participants or regulators. Against the background of a greater availability of real-time data and the provision of large amounts of data and its processing, price changes can be made even faster. Price signals as a form of communication can, therefore, foster collusion as they ease the coordination of cartel members.[80] In order to prevent such agreements, platform operators could impose time restrictions on traders so that they can only change their prices at certain intervals.[81] For example, sellers on an online platform could only adjust their prices twice a day or even less often. On that account, sellers no longer have an incentive to permanently change their prices for small benefits.

However, using time restrictions can lead to inefficiencies in the market as sellers are restricted in their price-settings. Another option is to incorporate lags in trading activities. In practice, this idea has led to the development of an electronic trading platforms which features so-called *speed bumps*. In 2016, the Investors Exchange (IEX), a national stock exchange for US equities, was launched with the purpose of slowing down

[78]Autorité de la Concurrence and Bundeskartellamt (n 34).
[79]OECD – Directorate for Financial and Enterprise Affairs (n 3).
[80]Vestager (n 2).
[81]Paolo Siciliani, 'Tackling Algorithmic-facilitated Tacit Collusion in a Proportionate Way' [2018] 10(1) Journal of European Competition Law & Practice 31.

communication between traders. The operators integrated a delay in trading activities by 350 microseconds, reducing the overall speed at which transactions take place.[82] This delay slows down all market participants at a minimal rate which matters for algorithms while at the same time, is not even observable by humans. This can not only hamper price coordination but also impede other illegal practices. Consequently, methods such as front-running are no longer profitable. These market manipulations are based on informational advantages by one trader over his competitors. Traders can use their knowledge about a future transaction in order to make a profit by placing an order ahead of a pending, large order which is expected to influence the price. Overall, small delays or restrictions in price changes can interfere with coordinated behaviour without deterring technological advances in automated trading.

5.3.3. Burden of proof

In the case of concrete indications of collusive behaviour, usually an investigation is carried out by the competent authority. In that event, it is suggested to introduce a change in regulation regarding the burden of proof.[83] Thereby, the user of the algorithm has to prove that running the software did not contribute to any kind of competition infringements. As a restriction, only anticompetitive behaviour over a longer period of time and in cases when consumers are not adequately protected against any disadvantages should be considered.[84] As stated by the German Monopolies Commission, this cautious approach seems appropriate since previous experiences have shown that pricing algorithms have only played a minor role in collusive agreements. Therefore, it recommends a comprehensive monitoring of markets before shifting the burden of proof. Positive effects can be expected for situations where liability questions arise which cannot easily be clarified. Then, the reversal could hold the users of the algorithms accountable for their actions. For example, if an investigation by the competent authority has revealed collusive prices whereupon financial losses for consumers occurred, the operator of the applied pricing algorithm is then obliged to provide evidence in his favour. This could also benefit the authorities as their workload decreases while it becomes easier to concentrate on market observation and detection of anticompetitive behaviour. On the downside, such legal

[82]Deutsche Bundesbank, 'Bedeutung und Wirkung des Hochfrequenzhandels am deutschen Kapitalmarkt' [2016] Deutsche Bundesbank, Monatsbericht Oktober 37.
[83]Ezrachi and Stucke, 'Algorithmic Collusion: Problems and Counter-measures' (n 17).
[84]German Monopolies Commission (n 8).

interventions could deter investments into the development and research of pricing software as investors might be put off by higher standards for accountability. Overall, we agree that a reversal of the burden of proof could be an effective tool for regulators if a thorough market observation reveals unambiguous signs of collusion.

6. Conclusion

Pricing algorithms have become an effective tool for retailers to optimize their price-setting in online and in traditional markets. Efficiency gains are beneficial for sellers on the one hand, but the potential use of algorithms to support and contribute to anti-competitive behaviour can be detrimental to consumers on the other hand. Firms can apply pricing software to maintain and stabilize cartels and constantly monitor the market for deviations. Also, algorithms could potentially collude with others by communicating prices, reaching an autonomous collusive outcome. This paper explores the conditions for algorithmic collusion, its likelihood and discusses some countermeasures.

Several structural market characteristics as well as the specific design of pricing algorithms can facilitate algorithmic collusion. In particular, similar and compatible algorithms are more likely to collude with each other as they feature similarly constructed decision-making processes. Given identical input data, these pricing algorithms could theoretically lead to collusive outcomes. In practice, however, such scenarios are rather unlikely. Due to changing market conditions and limited abilities of algorithms to communicate their pricings, algorithmic collusion as such is not realizable at this point in time. Therefore, the focus of research should concentrate on algorithms as a device to establish and maintain cartels. This does not constitute an entirely new problem but due to the greater availably of data and more sophisticated technological means, it has become more relevant. Prices can now be set faster, changes are made more frequently and deviations from agreements can be detected more effectively. This, in turn, can ultimately strengthen cartel stability as deviations are riskier and punishment can be implemented ad hoc. As recent cases have shown, maintaining an agreement with the help of computer software is an actual danger on online market platforms.

In order to prevent the application of pricing algorithms to facilitate collusion as well as algorithms to autonomously collude with each other, several countermeasures are discussed. Most importantly, timely detection and prosecution remains challenging. Regulatory authorities are therefore reliant on adequate technological equipment and well-trained staff. This is especially required in order to analyse large amounts of data for statistical purposes. Unexpected or unusual price movements could potentially lead to fixed prices and can only be detected with sufficient time-series of data and a highly-qualified workforce. Real-time market monitoring requires more resources for regulators and abilities to process large amounts of information at the same time.

In this context, national regulatory authorities should exchange information about possible misconduct with their counterparts in other jurisdictions. Strengthened international cooperation could enhance data collection and analysis. Moreover, by disclosing market information and reporting suspicious price movements, competent authorities ease tracking of anticompetitive behaviour across borders.

Also, in the aftermath of detecting collusive prices, algorithms enforced by competent authorities could be installed to destabilize the cartel by disrupting the collusive equilibrium. Algorithmic consumers can counterbalance the advantages of algorithmic price-setting as they help consumers to make better-informed choices. This could prevent collusive outcomes to emerge when consumers are able to inform themselves in real-time about price changes. In addition, a greater focus on white-box algorithms may benefit traceability of prices for consumers. The white-box approach promotes transparency in price-setting by allowing regulators to identify the structure and design of the algorithm and to comprehend pricing decisions.

Legislative action should only be considered in limited ways. Transparency obligations for developers and operators of the algorithms could provide more understandable pricing and provide disclosure for regulators. Furthermore, speed restrictions like small delays in price changes can potentially interfere with coordinated behaviour, without deterring technological advances. Additionally, a reform of regulation regarding the burden of proof could prove helpful. This means that the user of the algorithm has to prove that running the software did not contribute to any kind of competition infringements, easing the work of the competition authority.

All in all, the main challenges in dealing with algorithmic pricing consist of detecting anti-competitive behaviour. Competition authorities need adequate equipment and a skilled workforce in order to monitor markets and detect conspicuous features.

Disclosure statement

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