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Algorithmic competition – Note by Norway

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1. 1 Introduction

1. Technological advances have enabled firms to monitor and adapt to market conditions more effectively. With access to more data and greater computing power, firms can use various algorithms to automate their analysis of market trends. Algorithms are sets of operations that produce specific results when followed, like recipes for tasks or problems.

2. Firms can use pricing algorithms to automatically adjust prices based on market data. The algorithms can collect and respond to new information faster than humans. This can increase efficiency by helping firms adapt to changes in costs and demand. However, pricing algorithms may also harm competition, for example by facilitating tacit collusion.

3. In 2020, The NCA surveyed Norwegian retailers and software providers on the use of pricing algorithms.[1] The main results were that 20% of the surveyed firms let algorithms set the firm's prices. Furthermore, 55% of firms used algorithms to collect pricing information about competitors. [2] The most common input used in the price setting was competitors' prices. The respondents varied in how often they collect information about competitors' activities, ranging from several times a day to once per week, with daily collection being the most common.

4. Pricing algorithms were already widely used in Norway in 2020. Since then, technological progress has likely made them faster and more widespread. Therefore, the NCA works on a proactive strategy to deal with competition problems arising from algorithmic pricing. In the following we will present some observations in this regard. We focus on how pricing algorithms can increase prices, and structure the analysis using similar categories of harmful algorithmic pricing as Ezrachi and Stucke (2017),[3] but also rely on more recent literature:

- "Messenger": Humans in different firms initiate a classic cartel. Pricing algorithms are used to implement, monitor, and enforce cartel rules.
- "Predictable agent": Humans in different firms design predictable pricing rules that a pricing algorithm carry out. Pricing algorithms increase transparency in the market, provide faster price changes, and make it possible for firms to commit to a strategy over a certain period.
- "Autonomous machine": Self-learning algorithms set the prices for each firm. Humans only specify the algorithm's goal, usually to maximize the firm's profit. Each algorithm then learn over time which strategy is optimal, and algorithms setting prices for competing firms can learn to coordinate on high prices.
- "Hub and spoke": A software provider sells a pricing program to more than one firm in the same market. In some instances, the program uses information from

[1] Konkurransetilsynet (2021), "Hvilken effekt kan algoritmer ha på konkurransen?"

[2] 46% of the firms used algorithms to collect information. In addition, some firms purchased data from a third party.

[3] Ezrachi, A. and Stucke, M.E. (2017), "Artificial Intelligence & Collusion: When Computers Inhibit Competition" *U. Ill. L. Rev*.

multiple firms and may take account of all firms' profits when setting prices. The program may also have a fixed strategy, a default strategy that the firms can modify, or no default strategy but a limited range of available strategies.

5. A prerequisite for algorithmic pricing is that the algorithms are fed various data. The firms always have access to internal data, such as their own prices, and costs. External data, including competitors' prices, is however often not easily available. Different forms of sharing internal information with competitors can facilitate algorithmic pricing and are thus related to the potential harmful effects associated with algorithmic pricing.

6. Chapter 2 outlines the potential efficiency-enhancing and detrimental impacts of algorithmic pricing. Chapter 3 discusses how harmful algorithmic pricing can be remedied. Finally, Chapter 4 offers a summary and presents some concluding remarks.

2. Harms and benefits

7. Pricing algorithms have mixed effects on competition. They can make the market more efficient but can also weaken competition through various mechanisms. This chapter will briefly explore the positive and negative effects of pricing algorithms, using economic theory and empirical evidence.

2.1. Efficiencies

8. Pricing algorithms can lower the menu costs related to changing prices. A more significant effect is that the algorithms allow prices to adjust more quickly and efficiently to changing market conditions, also known as dynamic pricing. Dynamic pricing will usually result in higher prices when demand is high (or supply is low) and lower prices when demand is low (or supply is high), compared to a situation where prices change less often and manually. Dynamic pricing can increase the sales volume and the social welfare over time.

9. MacKay et al. (2022) examine the impact of introducing algorithmic pricing for home delivery of restaurant food for a large restaurant chain.[4] They find that pricing algorithms cause significant increases in short-term price fluctuations, but that prices on average decrease. Algorithmic pricing provides more precise alignment of pricing to short-term changes in demand and leads to higher prices and lower sales in periods when the demand is so high that supply-side capacity constraints become binding, and lower prices and higher sales in periods with low demand. More efficient pricing thus enables more optimal use of capacity and reduce various kinds of waste or idle resources and thus promote efficiency.

2.2. Competitive harm

2.2.1. Messenger

10. Pricing algorithms can enable firms to maintain explicit cartels more effectively.[5] Algorithms can follow agreed pricing rules and quickly detect and punish deviations. This

[4] MacKay, A., Svartbäck, D. and Ekholm, A. G. (2022) "Dynamic Pricing and Demand Volatility: Evidence from Restaurant Food Delivery", working paper.

[5] Competition & Markets Authority (2018), "Pricing Algorithms. Economic Working Paper on the Use of Algorithms to Facilitate Collusion and Personalized Pricing".

makes collusion more stable and profitable. Algorithms can also reduce the noise and uncertainty in price information that can undermine collusion. Finally, algorithms can prevent human employees from making pricing decisions that violate the cartel agreement.

11. To date, competition authorities have initiated a limited number of cases concerning horizontal collusion and pricing algorithms. A notable exception involves a cartel among firms selling poster on Amazon, which was prosecuted by both the Department of Justice in the US and the Competition and Markets Authority in the UK. The firms involved used pricing algorithms to execute their collusive strategy.

2.2.2. Hub-and spoke

12. Different firms in the same market may use the same algorithmic pricing program purchased from the same software provider. This can create a "hub and spoke" situation, where the pricing program (the hub) sets prices for several firms (the spokes). If the pricing program considers the profits of multiple competing firms when setting prices, the algorithm may charge higher prices than what each firm would want individually. The mechanism resembles the one explaining how horizontal mergers between competitors can reduce competition.

13. To initiate tacit collusion, firms need to agree on a common strategy - they need to find a focal point, such as setting the same price or following the same pricing strategy. This can be hard to do when market conditions are complex and there are many ways to collude.[6] Using the same pricing algorithm can be one way to agree on a common strategy and make the firms react in the same way to market changes.

14. If several firms use the same pricing program, and the program only allows one pricing algorithm (i.e., one pricing strategy), this can help firms coordinate on a common strategy and facilitate tacit collusion. Rather than only having one possible pricing strategy, the pricing program may have a default strategy that is used if a firm does not make any changes. This default strategy can make it easier for firms to anticipate which pricing strategies their competitors use and can become a focal point enabling firms to agree on the same pricing strategy. Pricing programs may also limit which strategies firms can choose. For example, the program may only allow strategies that match prices or other linear responses to competitors' prices.

15. The Department of Justice in the US is currently investigating a possible hub-and-spoke cartel using pricing algorithms in the residential rental market.[7]

2.2.3. Predictable agent

16. Pricing algorithms enable quick and predictable responses to competitors' price changes. Expectations of such responses may affect pricing incentives, which in turn may lead to higher prices through various mechanisms. In the following, we first examine how algorithms can facilitate "classic" tacit collusion, and then discuss how algorithms can increase prices by letting firms commit to (and coordinate on) a certain pricing strategy.

Classic tacit collusion

17. The swift and predictable adjustment of prices in response to competitors' price changes makes the punishment for deviating from the high collusive price more effective.

[6] Green E. J., Marshall, R. C. and Marx, L. (2014), Chapter 19 in "Tacit Collusion in Oligopoly", Oxford handbook of international antitrust economics, volume 2.

[7] The DOJ Has Opened an Investigation Into RealPage — ProPublica

As a result, tacit collusion becomes more stable, and prices can increase also without explicit cartel agreements.

18. Price leadership, a practice where one firm increases price first and the other firms quickly follow the leader, can help firms initiate tacit collusion. The leader enables coordination by deciding the new higher price level firms will coordinate on.[8] However, the leader may lose customers while waiting for the other firms to catch up to the higher price. Pricing algorithms can make this wait shorter and less costly, encouraging firms to use price leadership to raise prices.

Price-mimicking strategies

19. With algorithmic pricing each firm chooses an algorithm to effectively act as a "representative" for the firm, enabling firms to signal commitment to a pricing strategy.[9] Empirical evidence[10] show that firms often chose simple pricing strategies that mimic competitors' price changes, for examples strategies where firms match rivals price changes for more or less identical products.[11] In the following we briefly describe emerging research demonstrating how competition can be harmed when firms commit to such simple "leader-follower" or "tit-for-tat" pricing strategies.

20. Inspired by the pricing patterns observed in online pharmacies, Brown and MacKay (2023) explores a situation where firms compete by selecting price algorithms that respond to their competitors' prices at varying frequencies.[12] The authors show that firms adopt a leader-follower conduct where the slowest firms anticipates that the faster competitor will slightly undercut their price, and thus, sets a high price. The fast competitor then undercut the slow firm, but both firms' prices end up being significantly above the competitive price. Prices increase even though all firms act non-cooperatively to pursue their own self-interest; no explicit or tacit agreement is necessary, and a single firm can initiate higher prices simply by employing a superior pricing algorithm.

21. Lamba and Zhuk (2023) model a scenario in which firms equipped with fast algorithms can experiment to discern their competitors' algorithms.[13] They find that firms will coordinate on tit-for-tat strategies, resulting in prices that exceed the competitive outcome.

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[8] See e.g. Byrne, D. P. and de Roos, N. (2019), "Learning to Coordinate: a Study in Retail Gasoline", American Economic Review.

[9] MacKay, A. & Weinstein, S. (2022), "Dynamic Pricing Algorithms, Consumer Harm, and Regulatory Response", Wash. U. Law Review.

[10] Norman, H. T. & Sternberg, M. (2023), "Human-Algorithm Interaction: Algorithmic Pricing in Hybrid Laboratory Markets", European Economic Review.

[11] The "price-mimicking strategies" can also involve other strategies where firms change price in the same direction as competitors price changes, for example setting prices a certain percentage above/below a competitor or the average price of a set of competitors. Similar strategies can also feature in markets without pricing algorithms. See for example Lu and Wright (2010), "Tacit Collusion with Price-Matching Punishments", International Journal of Industrial Organization" showing that firms can coordinate on price matching strategies. In their model, faster response to competitors' price changes increase the collusive price level. Price-mimicking strategies are also related to price guarantees, see Brown & MacKay (2023).

[12] Brown, Z.Y. and MacKay, A. (2023), "Competition in Pricing Algorithms". AEJ: Microeconomics.

[13] Lamba, R. and Zhuk, S. (2023), "Pricing with Algorithms", working paper.

22. Leisten (2022) investigates a context where human managers can override pricing algorithms at a certain cost.[14] A low cost weakens the commitment to a specific pricing strategy, but supracompetitive prices may still emerge even when overriding is costless. Leisten's model can explain the asymmetric price cycles often observed in retail fuel markets and in some online markets; pricing algorithms progressively undercut one another until a manager manually overrides the algorithm, resetting the price to a higher level.

23. Musolff (2022) presents empirical evidence showing a notable increase in prices on Amazon Marketplace when firms adopt pricing algorithms that facilitate "resetting" strategies (regularly raising prices, e.g., during nighttime hours or when margins decrease to a certain threshold).[15] The implementation of these strategies results in asymmetric price cycles. The pricing software used by merchants only permits these types of resetting strategies, effectively preventing the use of alternative strategies. The author also introduces a theoretical model where the responsibility of resetting is delegated to algorithms rather than arising from managerial overrides, and the range of available strategies is constrained. In equilibrium, the average price is close to the monopolist price. Musolff concludes that the pricing software's limitations on the set of available strategies promote tacit collusion and higher prices.

24. Normann and Steinberg (2023) investigate pricing in laboratory markets when human players interact with an algorithm playing a simple tit-for-tat strategy. They observe significantly higher prices when one of three firms in a market is an algorithm, compared to human-only markets.

25. Assad et al (2023) study the adoption of pricing algorithms in the German retail gasoline market. They find that margins increase significantly in non-monopoly markets where all firms adopt algorithmic pricing.[16] The authors do not know which algorithms the firms use, but the post-adoption pricing pattern show that the algorithms meet competitor price decreases with an immediate price decrease of their own, teaching each other that undercutting is not profitable since the undercutter will always be followed to the lower price by the other station.[17] The German retail gasoline market is characterized by intra-day asymmetric price cycles. Similar price cycles are found in the retail gasoline market in many other countries, including in Norway.[18]

2.2.4. Autonomous machine

26. Sophisticated algorithms may experiment and learn over time which actions lead to the best result in a given situation. Such learning algorithms can be programmed to maximize a firms' profit, and then experiment and improve pricing strategies over time.

[14] Leisten, M. (2022), "Algorithmic Competition, with Humans", working paper.

[15] Musolff, L. (2022), "Algorithmic Pricing Facilitates Tacit Collusion: Evidence from E-Commerce", working paper.

[16] Assad, S., Clark, R., Ershov, D. and Xu, L. (forthcoming), "Algorithmic Pricing and Competition: Empirical Evidence from the German Retail Gasoline Market", Journal of Political Economy.

[17] The market is characterized by asymmetric price cycles. The authors do not find a faster response to price increases after adoption. One possible explanation for the asymmetric response to increases and decreases is that post-adoption, the response to price decreases are automated by fast algorithms, while large price increases (resets) are still initiated by managers as in Leisten (2022).

[18] Foros, Ø. and Nguyen-Ones, M. (2020), "Coordinate to obfuscate? The role of prior announcements of recommended prices", Economic Letters and Vedtak 2020-26 - Circle K Norge AS - konkurranseloven § 12 tredje ledd, jf. § 10 og EØS-avtalen artikkel 53 - Konkurransetilsynet

Recent research explore interaction between pricing algorithms in simulated markets with different characteristics. Calvano et al. (2020) show that algorithms playing a repeated game with simultaneous pricing can learn to charge supracompetitive prices supported by collusive strategies.[19] Klein (2021)[20] shows that a similar outcome can also occur under sequential pricing, and Johnson et al. (forthcoming)[21] show similar results for a platform market. Thus, the simulation-based evidence suggests that algorithms may learn to collude without human intervention. However, learning is slow and occurs over thousands of periods and the claim that algorithms learn to collude has been questioned by other researchers.[22]

27. Whereas the learning mechanisms behind these algorithms are hugely complicated, the strategies they produce are memory-one — a property they share with simple tit-for-tat strategies.[23]

28. There is currently sparse evidence of algorithms learning to collude in real-life markets. However, Assad et al. (2023) provide evidence consistent with algorithmic learning: The authors do not know which algorithms firms use, but margins in the German retail fuel market start to increase about a year after market-wide adoption of pricing algorithms, suggesting algorithms in the market learn collusive strategies over time.

3. Remedies to harmful algorithmic pricing

29. European competition regulations like TFEU Article 101 prohibits anti-competitive horizontal agreements between firms. Competition authorities can levy fines on infringing firms and can also require firms to bring infringements to an end. The fines create important deterrence effects. Additionally, they may implement structural or behavioral remedies to effectively put an end to the infringement.[24] Article 101 decisions also establish legal precedent that provide guidance on the interpretation of the law.

30. There are two main criteria for TFEU Article 101 to apply to horizontal agreements. First, there must be an agreement or concerted practice between actual or potential competitors. Second, the agreement must have as the object or effect the restriction of competition. Article 101 is well suited to handle cases where there is evidence of an agreement or concerted practice between firms, like explicit cartels using pricing algorithms to carry out the cartel's strategy, some hub-and-spoke related scenarios, and instances where firms have agreed to exchange price information that serve as an input in for algorithmic strategies.

31. One reason for requiring evidence of an agreement or concerted practice is the inherent difficulty in distinguishing whether the observed behaviour arise from competition

[19] Calvano, E., Calzolari, G., Denicolo V. and, Pastorello, S. (2020), "Artificial Intelligence, Algorithmic Pricing, and Collusion", American Economic Review.

[20] Klein, T. (2021). "Autonomous algorithmic collusion: Q-learning under sequential pricing", The RAND Journal of Economics.

[21] Johnson, J, Rhodes, A, Wildenbeest, M. (forthcoming), "Platform Design when Sellers Use Pricing Algorithms", Econometrica.

[22] den Boer, A. V, Meylahn, J. M, and Schinkel, M. P. (2022), "Artificial Collusion: Examining Supracompetitive Pricing by Q-Learning Algorithms", working paper.

[23] Normann & Sternberg (2023).

[24] See Remedies and Commitments in Abuse Cases, European Commission (2022).

or collusion. As Harrington (2019) puts it, pricing strategies are often latent, inside the managers' head.[25] This can make it hard for regulators to infer whether the underlying strategy firms employ is designed to harm competition. When prices are set by an algorithm, the firm's strategy is, in principle, observable: The rule determining price is written down in the algorithm's code which means that it can be accessed (in some manner) and, in that sense, it is possible to get "inside the head" of the price-setting agent.

32. The capacity to understand firms' strategies by analyzing pricing algorithms may make it easier to determine if firms' behavior restrict competition, even in cases with insufficient proof of an agreement or concerted practice.

33. Since 2001, the UK competition authorities have had the ability to conduct market investigations and implement necessary remedies if competition is found to be restricted. Norway and several other European countries, including Germany, Denmark, and Austria, are currently contemplating similar regulations. Given that pricing algorithms may facilitate anti-competitive behavior and the capability to understand algorithmic pricing strategies, it appears reasonable to tackle anti-competitive conduct involving pricing algorithms, even in the absence of sufficient evidence of an agreement or concerted practice. Market investigations, coupled with the potential to implement remedies, seem to be an effective approach for enabling such regulation. If the NCA is granted a market investigation tool akin to the one used in the UK, it will consider its use in situations where harmful algorithmic pricing is identified, in the absence of evidence of agreements or concerted practices.

34. In the following, we explore various remedies that can be employed to bring algorithm-related infringements of TFEU Article 101 to an end or as remedies in market investigations concerning algorithmic pricing. The main principle should be preventing anticompetitive effects while also minimizing obstruction of efficiency-enhancing effects (Harrington, 2019). Additionally, regulators should aim to minimize administrative expenses for both firms and regulators. Unclear remedies can result in compliance costs for firms, while remedies that are hard to monitor can be ineffective or incur significant enforcement expenses for the authorities.

3.1. Avoiding high market concentration

35. Mergers that increase market concentration can facilitate tacit collusion (Ivaldi et al., 2003).[26] Mergers can also increase prices in markets where firms employ algorithmic price-mimicking strategies (Brown & MacKay, 2023). Clearly, merger control should consider the impact of pricing algorithms on competition. Commentators have also suggested several measures to ensure stricter merger control in market with algorithmic pricing, including stricter requirements for merger notifications (Gahl, 2022 and Coutt, 2022).[27]

36. Decreasing market concentration can mitigate the negative impact of algorithmic pricing, meaning reducing barriers to entry can potentially be an effective remedy. For

[25] Harrington, J. E. (2019), "Developing Competition Law for Collusion by Autonomous Algorithmic Agents", Journal of Competition Law and Economics.

[26] Ivaldi, M., Jullien, B., Ray, P., Seabright, P. and Tirole, P., "The Economics of Tacit Collusion". Final report for DG Competition, European Commission.

[27] Gahl, M. (2022), "Limiting Algorithmic Cartels", Berkely Journal of Law and Technology. Coutt, M. D. (2022), "Mergers and Acquisitions and Merger Control in an Algorithmic Pricing World", Journal of Competition Law and Economics".

instance, incumbent firms could be required to provide new entrants with access to essential infrastructure or other critical input factors. While such a mandate can ease the entry process considerably, it may also be intrusive towards the firms who have invested in and own the infrastructure.

3.2. Prohibitions of certain types of pricing algorithms

37. A general ban on all pricing algorithms can preclude the efficiency gains described in Chapter 2.1 and can hamper the development of future more efficient pricing algorithms. Furthermore, the academic literature on algorithmic pricing is still nascent and is evolving at a rapid pace, and competition authorities have so far initiated few cases related to algorithmic pricing. Thus, the NCA believes there is also insufficient evidence to issue a general ban in all markets on specific types of pricing algorithms. However, the NCA believes that if a certain type of algorithmic pricing is found to restrict competition in a given market, a prohibition in this specific market can be considered.

38. According to Harrington (2019), there is still much research to be done on determining which strategies should be banned. However, he suggests that regulators can consider banning strategies aimed at influencing the future prices of competitors in situations where pricing algorithms have resulted in tacit collusion.

39. Similarly, a ban could also be relevant in situations with algorithm carrying out rapid price mimicking strategies. Prohibiting the use of competitors' prices as input in the algorithm would make it hard for firms to implement price mimicking strategies (and other collusive strategies) while still allowing firms to have frequent price updates in response to other factors such as demand shocks (Brown & MacKay, 2023). Compliance with such a regulation can, however, be difficult to monitor. Enforcement likely would require firms to submit their algorithms to the regulator to ensure that they are not relying on competitors' prices (MacKay & Weinstein, 2022).

3.3. Increasing the response time to competitors' price changes

40. The potential restriction of competition associated with algorithmic pricing is closely tied to the algorithms' ability to quickly adjust to competitors' price changes (see Chapter 2). One potential way to mitigate the restrictive effects of algorithmic pricing is to implement regulations that slow down the response time to price changes. There are several ways to achieve this:

41. Alternative 1: Regulate the timing of price changes. Such a regulation has been implemented in the retail fuel market in Perth, Australia, where gas stations are required to notify regulators of their next-day prices by 2:00 pm every day. The gas stations are required to keep the same prices for every twenty-four-hour period starting at 6:00 am.[28]

42. Alternative 2: Introduce delays in how quickly firms can adjust their own prices in response to changes in competitors' prices. For instance, algorithms could be required to wait at least 24 hours before changing their own price in response to detecting competitors' price increases.

43. Alternative 3: Restricting how often firms can collect information about their competitors' prices, such as by allowing the monitoring component of the pricing algorithm to retrieve competitors' prices only once a day or once per week. Another option is to prohibit the automated retrieval of competitors' prices entirely.

[28] A similar regulation has also been introduced in Austria.

44. In the following, we first consider the positive effects that will apply to all three alternatives. Then we will go through the potential negative aspects of each of the measures.

3.3.1. Potential positive effects of the remedies

45. All three proposals will result in an increased response time to competitors' price changes, and thus lead firms to anticipate a delay before competitors react to their price changes. In situations involving explicit or tacit collaboration, this has two primary implications. First, participants are incentivized to deviate from the high coordination price, as they can benefit from a lower price and increased demand for a longer period before competitors implement punitive measures.[29] Second, price leaders must maintain high prices for longer period before competitors can match, making it costlier and less appealing for firms to act as price leaders.

46. Longer response time can also eliminate or mitigate the restrictive effects associated with price-mimicking strategies. As the response time increases, commitment to the algorithm's pre-specified pricing strategy may erode because managers can override the algorithm's strategy faster than the algorithms can change its prices. Moreover, price-mimicking strategies are likely to become less effective because competitors respond slower or the probability of a response decreases, and the incentives to set high prices will decrease even if the ability to commit to the algorithms' strategy is not entirely eliminated by the regulation. The regulation can also lead all firms to have the same price update frequency, eliminating the adverse effects associated with asymmetric response times where the slower firm serves as the price leader.

47. Slower response times will result in learning algorithms requiring more time to experiment and refine their strategies. The literature suggests that such algorithms need tens of thousands of periods to agree on tacit collusion. If the length of each period increases, the likelihood of learning algorithms initiating tacit collusion decreases.

48. Finally, the regulations can allow the introduction of price comparison portals without the negative consequences related to higher price transparency among firms. Price portals can positively impact customers by reducing their search costs; however, there is typically concern that transparency also increases among firms who can easily monitor competitors' prices on the portal and rapidly respond to price changes.[30] Imposing restrictions on the frequency of price changes ensures that firms cannot react swiftly to price changes, even if they observe them on the portal.

3.3.2. Inefficient pricing

49. Regulations restricting the frequency of price changes can hinder algorithms to efficiently respond to short-term fluctuations in supply and demand. Alternative 1, which regulates when prices can be changed, will clearly prevent firms from adjusting prices in response to shifts in supply and demand between specified price change intervals. Alternative 2 and 3 only restrict firms' abilities to gather information about and respond to

[29] Relatedly, Johnson et al. (forthcoming) show that competition on platforms can improve by introducing demand-steering rules that reward firms that cut prices with additional exposure to consumers.

[30] See Luco, F. (2019), "Who Benefits from Information Disclosure?", The Case of Retail Gasoline", AEJ Microeconomics. If firms are somehow better informed than customers, a potential remedy can be to make sure that the information that is exclusive to firms is shared with customers.

competitors' prices, and thus, do not impede their ability to modify prices based on changes in other market conditions.

50. This problem of inefficient pricing may be substantial in markets with significant short-term fluctuations in costs and demand, for example restaurant food delivery or taxi markets. Issues may also emerge in markets where swift price adjustments are essential for managing products that experience rapid fluctuations in value, such as those with high perishability. In contrast, when conditions on both the supply and demand sides are relatively stable in the short run, there is less reason for worry.

51. If short-term changes can be predicted in advance, the problem of inefficient pricing can be mitigated by allowing firms to set a pricing plan for a specified period (MacKay and Weinstein, 2022).[31] An example of this is the Nordpool spot market for electricity, where power producers submit the price at which they are willing to sell electricity for each hour of the next day.

52. The anti-competitive effects of algorithmic pricing may also already have skewed prices away from efficient competitive level. Thus, the capacity for rapid price changes may not lead to effective pricing (MacKay & Weinstein, 2022).

3.3.3. Less complex pricing facilitating tacit collusion

53. A potential concern associated, in particular with regulation Alternative 1, is that restricting the frequency of price changes may decrease market complexity, and potentially make it easier to initiate tacit collusion by reduction in the complexity of coordination equilibria.

54. After a price frequency regulation was introduced in Perth, prices decreased during the first four months after the initiation of price frequency regulation but subsequently returned to prior levels (Wang, 2009).[32] Approximately ten years later, the largest chain in Perth employed price leadership to initiate tacit collusion (Byrne and de Roos, 2019). The chains successfully coordinated simultaneous price increases every Thursday, followed by concurrent 2-cent price reductions per day during the rest of the week. Coordinating the 2-cent price cuts would likely have been more difficult without the frequency regulation.

3.3.4. Compliance and monitoring

55. Implementing Alternative 1 will require that the regulator conducts an analysis to determine the optimal frequency for price changes. In some markets, a frequency of one change per day could be reasonable, while in others, shorter or longer intervals might prove more effective. Comparable assessments are necessary for Alternatives 2 and 3 as well.

56. With Alternative 1, it is essential that all firms establish their prices for a given period without knowledge of their competitors' prices for the same timeframe. To ensure compliance, the regulator can maintain a price database, akin to the fuel market in Perth. firms would be obligated to report their prices to this database before they become public and effective. For example, prices for day "t" could be required to be reported by 2:00 PM

[31] Alternatively. regulations can include a safety valve that allow firms to make additional price changes if e. g. costs have shifted beyond a specified threshold.

[32]Wang, Z., (2009) "(Mixed) Strategy in Oligopoly Pricing: Evidence from Gasoline Price Cycles Before and Under a Timing Regulation", Journal of Political Economy. In Austria, prices fell significantly after the price frequency regulation was introduced, see Becker, M. Pfeifer, G. and Schweikert, K. (2021), "Price Effects of the Austrian Fuel Price Fixing Act: A Synthetic Control Study", Energy Economics.

on day "t-1", with publication following at 4:00 PM on day "t-1". This solution allows authorities to efficiently monitor compliance with the mandate.[33]

57. With alternatives 2 and 3, monitoring compliance is more challenging. The regulator could examine firms' price changes, looking for patterns suggesting too rapid reactions to competitors' adjustments. However, distinguishing such responses from reactions to common shocks can be difficult. The most relevant monitoring method is likely for authorities to occasionally audit firms' pricing algorithms. As with monitoring bans on certain pricing strategies, this approach entails significant administrative costs and additional bureaucracy.

58. All three alternatives would be easy to discontinue if they do not yield the desired effects.

4. Concluding remarks

59. Algorithmic pricing is already quite prevalent and enable fast response to competitors' price changes and will likely become increasingly common and even faster in the future. The algorithms allow for rapid and precise adjustments to changes in market conditions. This can lead to substantial efficiencies in markets with considerable short-term supply and demand fluctuations.

60. However, economic theory suggests that algorithmic pricing can also restrict competition:

- Explicit cartels may become more stable when fast and consistent algorithms, rather than humans, manage pricing.
- Reaching a consensus on strategies for tacit collusion can be easier if several firms in the same industry employ the same pricing software. Competition may also be constrained if the pricing software factors in multiple firms' profits when setting prices.
- Tacit collusion can be more stable if algorithms swiftly identify and penalize deviations from high collusive prices. A rapid response to price changes also increases the appeal of using price leadership to initiate a new equilibrium with higher prices.
- Algorithmic pricing allows for a commitment to rapid price mimicking strategies and can make such strategies more efficient. When firms anticipate that competitors will quickly follow price changes, both upward and downward, they are incentivized to raise prices.
- Learning algorithms can manage to agree on collusive strategies with high prices without being instructed to do so by humans.

61. Furthermore, a growing body of empirical literature support the notion that algorithmic pricing can harm competition. Rapid price-mimicking strategies are recurring

[33] Another possibility is to require that firms change their prices at precisely the same moment, such as posting new prices at exactly 4:00:00 PM. If prices are altered simultaneously, the firms would not have the opportunity to respond to each other's price changes before the next period. However, given that algorithms can react to competitors' price changes extremely quickly, it may be challenging to ensure that no firms are slightly later than others, allowing them the chance to respond to competitors' new prices.

findings in the empirical studies. Use of the same pricing program among competing firm, can help facilitate coordination on the same type of price mimicking strategies.

62. The NCA is currently working on a project to identify harmful algorithmic pricing. The project will place special emphasis on price-mimicking strategies. Potential analyses for identifying detrimental algorithmic pricing may concentrate on market characteristics such as market structure and whether firms are selling homogenous products and analyzing pricing patterns to determine e. g. how fast firms are responding to competitors' price changes. The NCA is also actively developing the technological expertise required to collect and audit firms' pricing algorithms to directly understand firms' pricings strategy.

63. In some cases, TFEU Article 101 can be invoked to challenge harmful algorithmic pricing. In situations where an agreement or concerted practices cannot be proven to the requisite legal standard, market investigations followed by remedies may provide a suitable alternative. If the NCA is granted such a tool it will contemplate its use in situations where harmful algorithmic pricing is identified, even in the absence of evidence of agreements or concerted practices.

64. Banning specific types of pricing algorithms can help alleviate harm, but also runs the risk of eliminating the advantages of algorithmic pricing or introducing additional issues. Moreover, monitoring compliance with such measures may prove challenging for regulators. An alternative approach is to inhibit firms from reacting quickly to their competitors' price adjustments. There are various measures that can achieve this objective. The challenge lies in identifying measures that are easy to monitor and effectively slow down response to price changes without impeding the positive impacts of algorithmic pricing.

65. Regardless of whether TFEU Article 101 is employed or a market investigation is conducted, determining the most appropriate remedy, if any, requires a case-by-case assessment. In situations where algorithms limit competition by reacting immediately to competitors' price changes and market conditions remain relatively stable, the NCA may consider regulations that permit price adjustments only at predetermined intervals, such as once per day or week. In instances where market conditions exhibit greater variability, it could be more advantageous to restrict the frequency with which firms can access price information, even if this necessitates increased administrative efforts for monitoring purposes.