LIMITING ALGORITHMIC COORDINATION

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ABSTRACT

Recent studies have proven that pricing algorithms can autonomously learn to coordinate prices and set them at supra-competitive levels. The growing use of such algorithms mandates the creation of solutions that limit the negative welfare effects of algorithmic coordination. Unfortunately, to date, no good means exist to limit such conduct. While this challenge has recently prompted scholars from around the world to propose different solutions, many suggestions are inefficient or impractical, and some might even strengthen coordination.

This challenge requires thinking outside the box. Accordingly, this article suggests four (partial) solutions. The first is market-based and entails using consumer algorithms to counteract at least some of the negative effects of algorithmic coordination. By creating buyer power, such algorithms can also enable offline transactions, eliminating the online transparency that strengthens coordination. The second suggestion is to change merger review so as to limit mergers that are likely to increase algorithmic coordination. The next two are more radical, yet can capture more cases of such conduct. The third involves the introduction of a disruptive algorithm, which would disrupt algorithmic coordination by creating noise on the supply side. The fourth and final suggestion entails freezing the price of one competitor, in line with prior suggestions to address predatory pricing suggested by Aaron S. Edlin and others. The advantages and risks of each solution are discussed. As antitrust agencies around the world are starting to experiment with different ways to limit algorithmic coordination, there is no better time to explore how best to achieve this important task.

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TABLE OF CONTENTS

I. INTRODUCTION

Competition in the marketplace is the main tool used in our economy to promote consumer welfare.[1] For competition to take place, certain conditions must exist. It is well accepted that perfect competition ensues when a large number of firms selling similar products operate in markets characterized by price transparency and low entry barriers.[2] But what happens when the market conditions that were assumed to protect us from high prices have limited

1. TUWE LÖFSTRÖM, HILDA RALSMARK & ULF JOHANSSON, SWEDISH COMPETITION AUTH., COLLUSION IN ALGORITHMIC PRICING 8 (2021); *see generally* Ariel Ezrachi, *EU Competition Law Goals and the Digital Economy* 4–6 (Oxford Legal Stud. Rsch. Paper No. 17, 2018) (reviewing the goals of competition law in digital markets).

2. *See, e.g.*, John Roberts, *Perfectly and Imperfectly Competitive Markets*, *in* 3 THE NEW PALGRAVE: A DICTIONARY OF ECONOMICS, 837, 837 (1987).

effect, or even serve to limit competition and increase prices to supra-competitive levels? This is the potential effect of pricing algorithms—dynamic pricing software that sets the price for a product or service.[3]

The use of pricing algorithms in the commercial world is here to stay, and the number of firms employing these tools keeps growing.[4] Many U.S. firms report using pricing algorithms.[5] In the EU, 67% of firms who tracked their competitors on a daily basis reported doing so via algorithms, and 35% of such firms also used automatic repricing algorithms (with or without manual adjustments).[6] Frequent use of pricing algorithms is reported by, inter alia, online retail enterprises,[7] tourism and hospitality firms,[8] and petrol stations.[9] This is not surprising. Automating pricing cuts costs and saves resources by taking the human decision-maker out of the loop. Furthermore, by using predictive and strategic analytics, pricing algorithms enable firms to react to changing market conditions in a speedier and more sophisticated way.[10] Introducing automated pricing is also easy: for firms that lack the expertise or resources to develop such algorithms on their own, a growing industry of software intermediaries offer automated pricing services, promising to increase

3. Löfström et al., *supra* note 1, at 7–8, 10; ELENA DONINI, COLLUSION AND ANTITRUST: THE DARK SIDE OF PRICING ALGORITHMS 51 (2019), https://www.associazioneantitrustitaliana.it/wp-content/uploads/2020/10/Tesi-Elena-Donini.pdf.

4. U.K. COMPETITION & MKTS. AUTH., PRICING ALGORITHMS: ECONOMIC WORKING PAPER ON THE USE OF ALGORITHMS TO FACILITATE COLLUSION AND PERSONALISED PRICING 7 ¶ 1.2 (2018), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/746353/Algorithms_econ_report.pdf; Zach Y. Brown & Alexander MacKay, *Competition in Pricing Algorithms* 1 (Harv. Bus. Sch., Working Paper No. 20-067, 2020).

5. *See, e.g.*, Peter Seele, Claus Dlerksmeler, Reto Hofstetter & Marlo D. Schultz, *Mapping the Ethicality of Algorithmic Pricing: A Review of Dynamic and Personalized Pricing*, 170 J. BUS. ETHICS 697 (2021) (containing a review of uses of pricing algorithms).

6. EUR. COMM'N STAFF WORKING DOCUMENT, FINAL REPORT ON THE E-COMMERCE SECTOR INQUIRY: REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT 175 ¶ 603, (2017). https://ec.europa.eu/competition/antitrust/sector_inquiry_swd_en.pdf.

7. *Id.*

8. Arnoud V. den Boer*, Dynamic Pricing and Learning: Historical Origins, Current Research, and New Directions*, 20 SURVS. OPERATIONS RSCH. & MGMT. SCI. 1, 6 (2015); DONINI, *supra* note 3, at 7; Andrea Guizzardi, Flavio Maria Emanuele Ponsa & Ercolino Ranieri, *Advance Booking and Hotel Price Variability Online: Any Opportunity for Business Customers?*, 64 INT'L J. HOSP. MGMT. 85 (2017).

9. Stephanie Assad, Robert Clark, Daniel Ershov & Lei Xu, *Algorithmic Pricing and Competition: Empirical Evidence from the German Retail Gasoline Market* (CESifo, Working Paper No. 8521, 2020), https://ssrn.com/abstract=3682021.

10. ORG. FOR ECON. CO-OPERATION & DEV. (OECD), *Algorithms and Collusion: Competition Policy in the Digital Age*, 817 (Sept. 14, 2017), https://www.oecd.org/competition/algorithms-collusion-competition-policy-in-the-digital-age.htm.

a firm's revenues quickly and efficiently.[11] Given these benefits, why use any other pricing method?

Algorithms have been used for some decades to set prices. From a regulatory perspective, what makes them of interest now is that markets are being populated by new generations of pricing algorithms, powered by artificial intelligence. Such algorithms can learn to reach a given objective (such as maximizing profits) in dynamic environments without human intervention.[12] Put differently, these algorithms are capable of autonomously discovering a profit-maximizing price scheme.[13] As a result, as Ezrachi and Stucke argue, Adam Smith's "invisible hand" is displaced by the "digitalized hand."[14]

The problem is that pricing algorithms may change market dynamics and limit our ability to enjoy low, competitive prices.[15] Specifically, there is a growing and well-founded consensus that such algorithms can make it easier for competitors to coordinate prices, at least in some settings, leading to increased prices in markets where such coordination was previously much more difficult.[16] This troubling consensus is based not only on theoretical studies which highlight the traits of pricing algorithms and the ecosystem in which they operate, but on a growing body of experimental and empirical support. For example, a simulation study recently summarized in *Science* found that after repeated interactions, autonomous learning algorithms designed to maximize profits for each firm learned to coordinate on their own.[17] An empirical study of the German gasoline market showed that the use of pricing algorithms raised prices by 9–28%.[18] Quantum computing may further

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11. Assad et al., *supra* note 9, at 42.

12. *Id.* at 2–3.

13. *Id.* at 5.

14. ARIEL EZRACHI & MAURICE E. STUCKE, VIRTUAL COMPETITION: THE PROMISE AND PERILS OF THE ALGORITHM-DRIVEN ECONOMY 27 (2016).

15. *See generally id.*; Ariel Ezrachi & Maurice E. Stucke, *Artificial Intelligence & Collusion: When Computers Inhibit Competition*, 2017 U. ILL. L. REV. 1775 (2017) [hereinafter Ezrachi & Stucke, *Artificial Intelligence*]; Ariel Ezrachi & Maurice E. Stucke, *Sustainable and Unchallenged Algorithmic Tacit Collusion*, 17 NW. J. TECH. & INTELL. PROP. 217 (2020) [hereinafter Ezrachi & Stucke *Tacit Collusion*]; Salil K. Mehra, *Antitrust and the RoboSeller: Competition in the Time of Algorithms*, 100 MINN. L. REV. 1323 (2016).

16. *See* discussion *infra* Section II.B.

17. Emilio Calvano, Giacomo Calzolari, Vincenzo Denicolò, Joseph E. Harrington Jr. & Sergio Pastorello, *Policy Forum: Protecting Consumers From Collusive Prices Due to AI*, 370 SCI. 1040 (2020) [hereinafter Calvano et al., *Protecting Consumers*] (summarizing the study published in Emilio Calvano, Giacomo Calzolari, Vincenzo Denicolò & Sergio Pastorello, *Artificial Intelligence, Algorithmic Pricing, and Collusion*, 110 AM. ECON. REV. 3267 (2020) [hereinafter Calvano et al., *Artificial Intelligence*]).

18. Assad et al., *supra* note 9, at 4–5.

increase the attractiveness of pricing algorithms and their potential harm to consumer welfare.[19] These concerns, which were acknowledged by regulators around the world,[20] as well as the OECD,[21] raise a red flag for regulators.[22]

Despite the potent effects of algorithmic pricing, fully autonomous price coordination by algorithms is not captured under antitrust laws.[23] This is mainly because the application of antitrust is conditioned on the existence of an agreement between firms to coordinate trade terms—i.e., cartelistic conduct. Accordingly, use of an algorithm to strengthen a cartelistic agreement would fall under the law.[24] However, oligopolistic coordination—wherein each competitor sets his trade terms unilaterally yet takes into account the plausible reactions of his rivals—is not considered an agreement, and therefore is legal. While the potential harm resulting from oligopolistic coordination (also sometimes called conscious parallelism or tacit collusion) has long been acknowledged, its legality was partly based on the assumption that oligopolistic coordination is uncommon, given the rarity of the market conditions conducive to such conduct.[25] Algorithms change this assumption, increasing the likelihood of autonomous coordination without a prior agreement (hereinafter "algorithmic coordination").[26]

Against this backdrop, antitrust agencies around the world are starting to experiment with different ways to limit algorithmic coordination. Unfortunately, existing regulatory tools are insufficient for this purpose. This challenge has prompted scholars from around the world to suggest different

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19. *See, e.g.*, Apoorva Ganapathy, *Quantum Computing in High Frequency Trading and Fraud Detection*, 9 ENG'G INT'L 61 (2021) (noting that quantum computing can increase, inter alia, the speed at which the algorithm reacts to market changes, and its ability to engage in low-cost yet sophisticated analysis).

20. *See, e.g.*, FED. TRADE COMM'N, *FTC Hearing #7: The Competition and Consumer Protection Issues of Algorithms, Artificial Intelligence, and Predictive Analytics* (Nov. 13–14, 2018), U.K. COMPETITION & MKTS. AUTH, *Algorithms: How They Can Reduce Competition and Harm Consumers*, (Jan. 9, 2021), https://www.gov.uk/government/publications/algorithms-how-they-can-reduce-competition-and-harm-consumers/algorithms-how-they-can-reduce-competition-and-harm-consumers (noting that "collusion appears an increasingly significant risk if the use of more complex pricing algorithms becomes widespread"); JACQUES CRÉMER, YVES-ALEXANDRE DE MONTJOYE & HEIKE SCHWEITZER, EUROPEAN COMM'N—COMPETITION, COMPETITION POLICY FOR THE DIGITAL ERA 96 (2019), http://ec.europa.eu/competition/publications/reports/kd0419345enn.pdf.

21. OECD, *supra* note 10, at 18–31.

22. Under some circumstances, algorithms can help facilitate coordination with humans. We leave such instances for future research.

23. *Id.* at 33–42.

24. *See, e.g.*, United States v. Topkins, No. CR-15-00201 (N.D. Cal. Apr. 6, 2015).

25. *See* discussion *infra* Section II.B.

26. Michael Coutts, *Mergers, Acquisitions and Algorithms in an Algorithmic Pricing World* (2022) (on file with author).

solutions.[27] Yet, as elaborated below, many suggestions are inefficient or impractical. For example, suggestions that algorithms be tested by antitrust authorities to determine their effects on market prices[28] make it easier to detect coordination, but do not change its legal status. For the same reason, increasing the fault-based liability of developers or users of pricing algorithms[29] may also not capture algorithmic coordination, given that under current laws, the harms generated by them do not amount to legal wrongs. Some suggested solutions might even strengthen coordination. Take, for example, the proposal that algorithms be made transparent to all.[30] While transparency would help reveal cases where algorithms are used to create an illegal cartel, it could also help competitors overcome obstacles to coordination.[31] Suggestions for changing the law to regulate how algorithms can be designed and coded, so as to prohibit the mechanism that leads to algorithmic coordination (e.g., the parts of the code of the algorithm that lead to coordination) rather than focusing on its form (the presence or absence of an agreement),[32] tackle the root of the problem. Yet, this remedy runs the risk of limiting technological development. The same difficulty afflicts the most straightforward-sounding solution, namely prohibiting the use of pricing algorithms outright.

Fashioning a remedy for the problem of algorithmic coordination requires thinking outside the box. Accordingly, this paper suggests four partial solutions. The first is market-based: using consumer algorithms to counteract at least some of the negative effects of coordinating algorithms. Such algorithms can also enable offline transactions, overcoming the effects of online transparency, which strengthens coordination. The role of the regulator in this first solution is limited to ensuring that obstacles to the operation of such consumer algorithms are low. The second suggestion requires slightly more regulatory intervention: shape merger review so as to limit mergers that are likely to increase algorithmic coordination. This remedy is in line with the suggestion by Glen Weyl and Eric Posner in their book, *Radical Markets*,[33] that we can fundamentally reduce consumer harm in digital markets through

27. *See* discussion *infra* Part III.

28. *See, e.g.*, Francisco Beneke & Mark-Oliver Mackenrodt, *Artificial Intelligence and Collusion*, 50 IIC-INT'L REV. INTELL. PROP. & COMPETITION L. 109, 132 (2017); Calvano et al., *Protecting Consumers*, *supra* note 17, at 1040.

29. *See, e.g.*, H.R. 2231, 116th Cong. (2019) (enacted).

30. Lea Bernhardt & Ralf Dewenter, *Collusion by code or algorithmic collusion? When pricing algorithms take over*, 16 EUR. COMPETITION J. 312, 335 (2020).

31. *See* discussion *infra* Section III.B.

32. *See, e.g.*, Calvano et al., *Protecting Consumers, supra* note 17, at 1042.

33. Glen Weyl & Eric Posner, Radical Markets: Uprooting Capitalism and Democracy for a Just Society (2019).

innovative application of existing laws.[34] The other two suggestions are more radical, yet can capture more cases of algorithmic coordination. The third involves the introduction of a disruptive algorithm in markets characterized by algorithmic coordination; and the fourth entails freezing the price of one competitor, in line with prior suggestions to address predatory pricing by Edlin and others.[35] Importantly, the adoption of these last two remedies is not necessarily advocated. Rather, this Article aims to generate a discussion on tools for limiting the harms of algorithmic coordination, a goal that thus far seems beyond both traditional and novel solutions.

In what follows, Part II of the Article first reviews recent developments in the economic literature regarding the use of AI-powered pricing algorithms. Part III then analyzes the limited ability of traditional regulatory tools and Part IV discusses the remedies suggested so far to limit such harms. Part V then describes the four proposed solutions. The discussion outlines the rationale behind each solution, lays out conditions for their application, and points to possible virtues and problems.

II. PRICING ALGORITHMS: MOVING MARKETS FROM COMPETITION TO COORDINATION

A. PRICING ALGORITHMS: DEFINITIONS, TOOLS, AND TYPES

A pricing algorithm is a sequence of computational steps that use data inputs to set prices for a product or service (hereinafter together "product").[36] The inputted data can relate to a myriad of parameters, including one's own current and foreseeable production costs, and the prices, production capacity, and storage capacity of rivals. The algorithm applies decision procedures to the data, such as predictive analytics and optimization.[37] Such robo-economicus can be programmed to maximize any variable, based on the inputted data and their decision tools.

Algorithms can operate at different levels of abstraction.[38] At the lowest level, all parameters and optimal responses to specific contingencies are dictated by the developer in advance (so called "expert algorithms").[39] As such,

34. *Id.*

35. Aaron S. Edlin, *Stopping Above-Cost Predatory Pricing*, 111 YALE L.J. 941 (2002).

36. OECD, *supra* note 10, at 16; Shuchi Chawla, Jason D. Hartline & Robert Kleinberg, *Algorithmic Pricing via Virtual Valuations*, *in* EC '07: PROCEEDINGS OF THE 8TH ACM CONFERENCE ON ELECTRONIC COMMERCE 243 (2007).

37. *See* THOMAS H. CORMEN, CHARLES E. LEISERSON, RONALD L. RIVEST & CLIFFORD STEIN, INTRODUCTION TO ALGORITHMS 5, 192–93, 843–49 (3d ed. 2009).

38. Michal S. Gal, *Algorithms as Illegal Agreements*, 34 BERKELEY TECH. L.J. 67, 84–87 (2019).

39. *See* OECD, *supra* note 10, at 11–12.

they require a human to direct the software to execute a task.[40] At the highest level, algorithms are designed to set or to refine their own decision parameters in accordance with inputted data and the decision-making techniques they are coded to perform ("learning algorithms").[41] Learning algorithms employ machine learning—a type of artificial intelligence that gives computers the ability to learn from data inputs without the need to define correlations a priori, allowing them to autonomously determine their decisional parameters.[42] In reinforcement learning, for example, the algorithm devises and tests different actions, taking into account the feedback from previous rounds in each subsequent round. That is, it follows a trial-and-error strategy, balancing actions that will maximize the payoff based on its current knowledge with random actions that may entail sacrificing a short-term payoff for the sake of improving future gains.[43] Such methods allow algorithms to autonomously learn rules that will best help them achieve their stated goal, even without human intervention.[44]

Algorithms offer significant advantages in decision-making. They significantly speed up the collection, organization, and analysis of data, enabling exponentially quicker decisions and reactions to changing conditions.[45] They also offer analytical sophistication, potentially also enabling them to devise new strategies for reaching a goal.[46] They can be used in a myriad of tasks, such as determining efficient levels and locations for production and storage, assessing risk levels, and, of course, pricing decisions.[47] Although the use of pricing algorithms is not new, as elaborated below, changes in the digital ecosystem have affected their operation and made

40. Emilio Calvano, Giacomo Calzolari, Vincenzo Denicolò & Sergio Pastorello, *Algorithmic Pricing What Implications for Competition Policy*?, 55 REV. INDUS. ORG. 155 (2019).

41. *See, e.g.*, OECD, *supra* note 10, at 9–11. For examples of machine learning already used in algorithms, see Ezrachi & Stucke, *Artificial Intelligence, supra* note 15, at 1780–81.

42. *See generally* TOM MITCHELL, MACHINE LEARNING (1997). Other types of artificial intelligence include, for example, expert systems, which use databases of expert knowledge to offer advice or make decisions in such areas as medical diagnosis or stock exchange trading.

43. BUNDESKARTELLAMT & AUTORITÉ DE LA CONCURRENCE, *supra* note 20; Löfström et al., *supra* note 1, at 14–20.

44. Calvano et al., *Protecting Consumers, supra* note 17, at 1040.

45. *See, e.g.*, OECD, *supra* note 10, at 15; PATRICK GROTHER, MEI NGAN, & KAYEE HANAOKA, U.S. DEPARTMENT OF COMMERCE, ONGOING FACE RECOGNITION VENDOR TEST (FRVT) PART 2: IDENTIFICATION (2018) (discussing the speed at which algorithms perform facial recognition).

46. *See, e.g.*, Matthew Adam Bruckner, *The Promise and Perils of Algorithmic Lenders' Use of Big Data*, 93 CHI.-KENT L. REV. 3 (2018); Ulrich Schwalbe, *Algorithms, Machine Learning, and Collusion*, 14 J. COMPETITION L. & ECON. 568, 591 (2018).

47. *See* OECD, *supra* note 10, at 16.

them both cheaper and more efficient.[48] It is thus not surprising that the use of pricing algorithms is spreading fast.

To reduce confusion, let us distinguish the case we deal with from others. Ezrachi and Stucke identified four scenarios in which algorithms can be used for pricing decisions.[49] The first involves their use to implement, monitor, police, or strengthen a prior, explicit agreement among suppliers. In such situations, an anti-competitive agreement exists between the users of the algorithms, and the algorithms simply serve as tools for its execution. This can be exemplified by the *Topkins* case, in which Topkins and his co-conspirators designed and shared dynamic pricing algorithms, which were programmed to act in accordance with their illegal agreement.[50] The second scenario involves hub-and-spoke arrangements, where many firms rely for their pricing decisions on the same pricing services provider, which uses a pricing algorithm.[51] For example, in the *Ageras* case, the Danish Competition Council found that a digital platform for professional services created an illegal cartel when its algorithm suggested minimum prices that service providers should charge clients on the platform.[52] The third scenario involves use of an expert algorithm in a way that can be expected to create or strengthen price coordination (e.g., a leader-follower algorithm).[53] This scenario also encompasses use of semi-expert algorithms, where the programmer does not

48. *See infra* Section II.B.

49. EZRACHI & STUCKE, *supra* note 14, at 35–82.

50. Press Release, U.S. Dep't Just., *Former E-Commerce Executive Charged with Price Fixing in the Antitrust Division's First Online Marketplace Prosecution* (Apr. 6, 2015), https://www.justice.gov/opa/pr/former-e-commerce-executive-charged-price-fixing-antitrust-divisions-first-online-marketplace; *see also* U.K. GAS & ELEC. MKTS AUTH, INFRINGEMENT BY ECONOMY ENERGY, E (GAS AND ELECTRICITY) AND DYBALL ASSOCIATES OF CHAPTER I OF THE COMPETITION ACT 1998 WITH RESPECT TO AN ANTI- AGREEMENT (July 26, 2019), https://www.ofgem.gov.uk/sites/default/files/docs/2019/07/decision_on_economy_energy__e_gas_and_electricity_dyball_associates_infringement_of_chapter_i_ca98_doorstep_sales_redacted_decision_document_26_july_2019.pdf (describing how two energy suppliers used a third party software developer to facilitate the distribution of customers among themselves, where the software developer contributed through designing, implementing and maintaining software systems that allowed the acquisition of certain customers to be blocked and customer lists to be shared).

51. EZRACHI & STUCKE, *supra* note 14, at 46–55. For their economic effects, see, e.g., Joseph E. Harrington Jr, The Effect of Outsourcing Pricing Algorithms on Market Competition 2 (July 19, 2021), https://ssrn.com/abstract=3798847.

52. Press Release, Danish Competition and Consumer Auth., *Danish Competition Council: Ageras has infringed competition law* (June 30, 2020), https://www.en.kfst.dk/nyheder/kfst/english/decisions/20200630-danish-competition-council-ageras-has-infringed-competition-law/.

53. *See* EZRACHI & STUCKE, *supra* note 14, at 56–70; Ilgin Isgenc, *Competition Law in the AI ERA: Algorithmic Collusion under EU Competition*, 24 TRINITY C.L. REV. 35, 40–42 (2021).

explicitly dictate the algorithm's strategy, but feeds it clues as to how it should behave in a way that biases the algorithm's learning process towards coordination.[54]

This Article does not deal with these cases, in which coordination is achieved by using algorithms that produce predictable outcomes, and that require at least some human involvement in determining how one competitor reacts to another.[55] To paraphrase Bernhardt and Dewenter, these cases can be called "coordination with code."[56] Instead, this Article focuses on the most difficult case, "coordination by code," in which the algorithm itself adopts price coordination as the most profitable strategy. In this scenario, the algorithm is given a goal (e.g., profit maximization), and independently and autonomously determines its own pricing strategies.[57] Take, for example, the extreme case where the algorithm does not even directly observe rivals' prices in the market, but simply observes through trial and error the demand reactions to the prices it sets, and determines which price maximizes revenues. Not only does coordination in such cases occur without human involvement, but the workings of such algorithms are typically highly complex and opaque, making it difficult to understand the logical reasoning behind the process.[58]

B. CAN ALGORITHMS COORDINATE PRICES AUTONOMOUSLY?

Can algorithms actually coordinate prices autonomously in real life, or is this science fiction? Until recently, the common wisdom among economists was that algorithmic coordination is unlikely to arise in practice without explicit communication, especially under dynamic real-world conditions.[59] Some economists have even argued that, assuming complete knowledge of market

54. John Asker, Chaim Fershtman & Ariel Pakes, *Artificial Intelligence, Algorithm Design and Pricing,* 112 AER PAPERS & PROC. 452, 455 (2022).

55. *See* EZRACHI & STUCKE, *supra* note 14, at 71–82. The article also does not deal with cases in which the algorithm increases the potential for unilateral anti-competitive conduct, such as predatory pricing. *See* Christopher Leslie, *Predatory Pricing Algorithms*, 97 NYU L. REV. (forthcoming 2023).

56. Bernhardt & Dewenter, *supra* note 30, at 315.

57. Ezrachi & Stucke, *Artificial Intelligence*, *supra* note 15, at 1794–96.

58. *See, e.g.*, Davide Castelvecchi, *Can We Open the Black Box of AI*, 538 NATURE NEWS 20, 21 (2016) (characterizing deep learning and neural networks "as opaque as the brain").

59. *See, e.g.*, Ashwin Ittoo & Nicolas Petit, *Algorithmic Pricing Agents and Tacit Collusion- A Technological Perspective*, *in* L'INTELLIGENCE ARTIFICIELLE ET LE DROIT 241, 241 (Hervé Jacquemin & Alexandre de Streel eds., 2017)("While we do not deny the fact that smart pricing agents can enter into tacit collusion . . . , we find that there are several technological challenges . . . that mitigate that risk."); Schwalbe, *supra* note 46, at 572–73, 590, 592–94.

conditions, the "digitalized invisible hand" may make prices more competitive, not less.[60]

Yet, based on groundbreaking research developments over the past two years, there is growing and strong consensus that some algorithms operating in today's digital ecosystem can indeed overcome some barriers to coordination under some circumstances, and raise prices. According to a recent article in *Science*, "enough evidence has accumulated that autonomous algorithmic [coordination] is a real risk."[61]

Before we survey this body of research, a word about definitions is in order. Economists use the term "collusion" indiscriminately in a way which refers to a joint profit maximization strategy put in place by competing firms and focuses on the final coordinated outcome.[62] Accordingly, it includes both illegal cartelization and legal oligopolistic coordination. Legal scholars use the term more narrowly (some use the term, by itself, to refer only to the former). Thus, to limit confusion, the term "collusion" is used in this Article only in its restricted sense, to refer to illegal cartelization, while applying the term "coordination" to oligopolistic coordination.

Theoretical research has identified a number of attributes of today's algorithms, and of the digital world in which they operate, that under some market condition foster coordination and create a more durable supra-competitive equilibrium, one that is not limited to marginal cases.[63] Six main factors are reviewed herewith. The first is the greater availability of relevant data—a necessary input for learning algorithms. The move of many industries to online commerce, coupled with the high speeds and low costs of internet connectivity, computing power, and data storage, have made data on rivals' prices and other trade conditions (such as non-price competition aspects and reaction of consumers to different trade terms) more accessible than ever before.

Second, and relatedly, the speed at which today's algorithms can operate has increased the speed at which firms can detect and react to changes in market conditions.[64] This, in turn, implies that when transactions are small and

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60. DONINI, *supra* note 3, at 90; *see also* Alexander Stewart-Moreno*, EU Competition Policy: Algorithmic Collusion in the Digital Single Market*, 1 YORK L. REV. 49, 67 (2020).

61. Calvano et al., *Protecting Consumers, supra* note 28, at 1041.

62. *See* George J. Stigler, *A Theory of Oligopoly*, 72, J. POL. ECON. 44 (1964); OECD, UNILATERAL DISCLOSURE OF INFORMATION WITH ANTICOMPETITIVE EFFECTS 20 (2012), www.oecd.org/daf/competition/Unilateraldisclosureofinformation2012.pdf (using the term collusion to refer to any coordinated conduct).

63. *See, e.g.*, EZRACHI & STUCKE, *supra* note 14, at 61–64; Gal, *supra* note 38, at 81–90. For some reservations, see Ittoo & Petit, *supra* note 58, at 241, 256; Schwalbe, *supra* note 46, at 572–75.

64. DONINI, *supra* note 3, at 58–60.

frequent, prices are transparent, and price changes are cheap, price reductions can be immediately detected and matched, thereby making them unprofitable.[65] The need for trust is also reduced when deviations can be quickly and more reliably detected.[66]

Third, the analytical sophistication of today's algorithms increases their ability to extract information from big data, enabling them to better predict demand as well as the likely reactions of rivals to changes in market conditions (including their own prices), and to determine the optimal price equilibrium in a dynamic environment.[67] This sophistication can reduce the risk of making pricing mistakes.[68] Furthermore, as Coutts argues, "algorithms can help firms navigate market complexity by elucidating potential focal points or collusive strategies in markets whose joint-profit maximizing equilibria sit just outside human cognitive capacity."[69] This is supported by theoretical economic models recently published by Abada and Lambin[70] and Brown and MacKay,[71] which found that when all firms employ pricing algorithms, simple linear strategies can support supra-competitive prices. Of course, algorithmic sophistication may also help facilitate deviations from the market equilibrium ("cheating") that are not easy to detect, for example, endogenizing the offer via loyalty rebates or complementary products. Accordingly, much depends on the conditions for sales in the market and the ability of other sellers to detect and to react to such deviations.

Fourth, the fact that the algorithm is a "recipe for action" makes its decision-making transparent (either directly or indirectly) and enables others to "read its mind," thereby reducing uncertainty with regard to the reactions of its rivals[72] and increasing the credibility that such actions will indeed take

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65. Gal, *supra* note 38, at 88–89.

66. Mehra*, supra* note 15, at 1361; *see also* Guy Sagi, *The Oligopolistic Market Problem: A Suggested Price Freeze Remedy*, 2008 COLUM. BUS. L. REV 269, 298 (2008) ("The marginal time span from the act of deviation to the rivals' retaliation (as we assume is the case in collusive oligopoly markets) practically eliminates the boxes where one firm has low payoff and the other firms have high payoff in the oligopoly payoff matrix.").

67. Research into online markets suggests that when price competition is limited, firms compete more over non-price aspects (such as quality or return policies). Algorithms might be designed to take differences in such features, and their perceived effects on consumers' choices, into their calculations.

68. Peter Georg Picht & Benedikt Freund, *Competition (Law) in the Era of Algorithms*, 6 (Max Planck Inst. For Innovation & Competition, Rsch. Paper No. 18-10, 2018).

69. Coutts, *supra* note 26, at 7.

70. Ibrahim Abada & Xavier Lambin, Artificial Intelligence: Can Seemingly Collusive Outcomes Be Avoided? 1 (Feb. 15, 2020), https://ssrn.com/abstract=3559308 (finding such a result when rivals observe only market prices rather than the direct actions of rivals).

71. Brown & MacKay, *supra* note 4, at 32–33.

72. Gal, *supra* note 38, at 84–87.

place without the need for repeated interactions.[73] Such decision-making transparency, coupled with the increased transparency of market conditions (including prices) in digital ecosystems, serves to reduce one of the main obstacles to coordination: imperfect information regarding rivals' probable reactions to one's actions.[74] It also changes the mode of communication needed to achieve coordination. Indeed, as Tennenholtz, has shown in another context, this implies that coordination can often be achieved in a one-shot game.[75]

Fifth, as Brown and MacKay have shown, the use of different pricing algorithms across firms endows some firms with a technological advantage that can discourage rivals from lowering prices in an attempt to gain market share, encouraging a follow-the-leader dynamic, which leads to higher prices for all firms.[76] Finally, pricing algorithms are within reach of firms of all sizes, in all industries. Firms can create their own pricing algorithms at a reasonable cost using freely available complex algorithms (including algorithms based on neural networks). Alternatively, they can rely on sophisticated algorithms operated or supplied by third parties.[77] Some examples include Repricer[78] and Inoptimizer,[79] both of which are AI-powered pricing algorithms. The combined effect of these conditions, it is argued, is that in some markets pricing algorithms improve market players' ability as well as their incentive to coordinate.[80] While their greatest impact may be on markets for commoditized products with perfectly substitutable offerings from competitors and small, frequent transactions, they may facilitate coordination even when markets are less concentrated, firms are less homogenous, and market conditions are more complex than generally assumed to be necessary for coordination.[81]

One way to appreciate the effect of pricing algorithms on market dynamics is through their effects on the barriers to coordination that are recognized in

73. For the importance of reputation for truthfulness, see Dennis W. Carlton, Robert H. Gertner & Andrew M. Rosenfeld, *Communication Among Competitors: Game Theory and Antitrust* 5 GEORGE MASON L. REV. 423, 436 (1997).

74. *See* OECD, *supra* note 10, at 21–22.

75. Moshe Tennenholtz, *Program Equilibrium*, 49 GAMES & ECON. BEHAV. 363, 364 (2004).

76. *See* Brown & MacKay, *supra* note 4, at 1–3 (arguing that the intuition is that the slow firm recognizes that the fast firm will always beat its price, so it gives up on trying to have the lowest price; instead, it picks its price while internalizing how the faster firm will react).

77. Assad et al., *supra* note 9, at 42.

78. Amazon Repricing Software for Price Optimization & Intelligence, FEEDVISOR, https://feedvisor.com/amazon-repricer/ (last visited Jan. 6, 2022).

79. *Inoptimizer*, INTELLIGENCE NODE, http://www.intelligencenode.com/products-inoptimizer.php (last visited Jan. 6, 2022).

80. *See, e.g.*, Gal, *supra* note 38, at 89; Coutts, *supra* note 26.

81. Gal, *supra* note 38, at 89.

the economic literature. Nobel laureate George Stigler identified three cumulative conditions that must exist for coordination to take place: reaching an understanding that is profitable for all parties, timely detection of deviations, and a credible threat of retaliation that will deter such deviations.[82] As elaborated elsewhere, algorithms may assist firms in fulfilling each of these conditions.[83] Take, for example, the availability of information regarding market conditions: the noisier or more incomplete the information, the harder it is to coordinate.[84] As Green and Porter have shown, this is partly because demand fluctuations make it more difficult to set a stable, jointly profitable price, and also make detection of deviations much harder, thereby increasing the chance of a price war.[85]

Consider the following example: a supplier observes that demand for his product is reduced. He cannot effectively differentiate between natural changes in consumer demand, which are likely to affect all suppliers in the market (or even mainly his product if products are heterogeneous), and deviations from the status quo by a competing supplier. Both possibilities may lead the supplier to lower his prices, potentially triggering a price war. It may take time until coordination is once again achieved, if at all. Accordingly, the more imperfect the price signals among suppliers, the less stable the coordination. Now, add algorithms operating in a digital marketplace. The increase in the velocity of veritable information, coupled with the sophistication of algorithms, may lead to fewer errors and better coordination. Algorithmic sophistication also makes it easier to more quickly and efficiently solve the multidimensional problems raised by coordination, such as establishing a jointly profitable price in a market with differentiated products.[86] Indeed, studies performed by Google's artificial intelligence business, DeepMind, on algorithmic interactions found that algorithms with more cognitive capacity sustained more complex cooperative equilibria.[87] Another example relates to Stigler's third condition—making deviations unprofitable. Cooper and Kuhn show that explicit threats to punish cheating are the most important factor in successfully establishing coordination among humans,

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82. Stigler, *supra* note 62, at 48–59.

83. Gal, *supra* note 38, at 81–90.

84. *See* Schwalbe, *supra* note 46, at 12.

85. Edward J. Green & Robert H. Porter, *Noncooperative Collusion under Imperfect Price Information*, 52 ECONOMETRICA 87, 94–95 (1984).

86. Gal, *supra* note 38, at 82.

87. Joel Z. Leibo, Vinicius Zambaldi, Marc Lanctot, Janusz Marecki & Thore Graepel, *Multi-agent Reinforcement Learning in Sequential Social Dilemmas*, *in* PROCEEDINGS OF THE 16TH INTERNATIONAL CONFERENCE ON AUTONOMOUS AGENTS AND MULTIAGENT SYSTEMS 464, 471 (2017).

once a cooperative strategy is established.[88] In the case of algorithms, the mere direct or indirect transparency of the algorithm, which includes a contingency for reaction in case a competitor changes his price, can communicate to competitors future intended actions.

Some scholars have challenged these theoretical studies, arguing that complexities often found in the real world reduce the probability of algorithmic coordination.[89] They point to the structural characteristics that best support coordination, which may not exist (e.g., a small number of competitors, homogeneous products, market transparency, and small and frequent purchases), as well as to design-related complexities (such as the time needed to train the algorithm to make decisions, and the computational challenges when numerous variables are introduced).[90] They conclude that algorithmic pricing only facilitates coordination in markets that are already conducive to [oligopolistic coordination], such that pricing algorithms simply removed the last obstacle to it.[91] Yet even if one accepts this claim, the question remains how many markets are on the verge of coordination. Furthermore, the growing sophistication of learning algorithms may lead to new coordination strategies, in which traditional obstacles are not relevant. Recall the two algorithms that learned to play chess simply by simulating millions of games in which they played against each other in the lab.[92] The algorithms created such effective strategies that they beat the world champion.[93] Is coordination under complex market conditions much more difficult? Finally, and most importantly, while some of the obstacles to coordination may not be affected by algorithms (e.g., the number of competitors in the market), others are being constantly improved by computer and data scientists (e.g., the level of sophistication of machine learning, the time and computing power it takes to analyze data) or by conditions in the digital economy (e.g., market transparency).

Of course, this does not imply that algorithms will enable coordination in all or even most markets.[94] Coordination might be especially difficult, for

88. David J. Cooper & Kai-Uwe Kühn, *Communication, Renegotiation, and the Scope for Collusion*, 6 AM. ECON. J. MICROECONOMICS 247, 268 (2014).

89. Ittoo & Petit, *supra* note 59, at 241.

90. *Id.* at 253–56.

91. *Id.* at 243.

92. Julian Schrittwieser, Ioannis Antonoglou, Thomas Hubert, Karen Simonyan, Laurent Sifre, Simon Schmitt, Arthur Guez, Edward Lockhart, Demis Hassabis, Thore Graepel, Timothy Lillicrap & David Silver, *Mastering Atari, Go, Chess and Shogi by Planning with a Learned Model*, 588 NATURE 604 (2020)

93. *Id.*

94. Ittoo & Petit, *supra* note 59, at 243 (arguing that current examples of known coordinations facilitated by algorithms occurred in markets where the algorithm removed the last obstacle to coordination); Cento Veljanovski, *Pricing Algorithms as Collusive Devices* (Inst. Of

example, when firms engage in discriminatory pricing based on personalized profiles,[95] products are semi-differentiated, transactions are far apart and large, firms have multi-market contact, transactions in one market have significant spillovers on other markets in which the seller operates (e.g., network effects), or prices or transactions are not transparent (e.g., in private auctions). Indeed, up until now, all studies of algorithmic coordination have generated proof-of-concept in simple market settings with commoditized goods. Nonetheless, it seems likely that algorithms could lead to price coordination in more cases than before, while reducing the need for direct communication among competitors.[96] This is especially true in digital markets with numerous asynchronous small transactions, with no spillovers into other markets and immediate information on one's rival's prices.

Indeed, recent computer simulation studies have discovered the emergence of autonomous coordination under some market conditions, suggesting that autonomous coordination by pricing algorithms is a real possibility. Most notably, in a seminal study, Calvano et al. show that commonly used reinforcement learning algorithms ("Q-learning"), which experiment with random actions and adapt their decisional rules accordingly, learned to initiate and sustain a supra-competitive equilibrium through a repeat-play reward-punishment scheme in an environment characterized by simultaneous pricing and repeated price competition, where each algorithm was instructed only to maximize its profits.[97] Coordination arose with no human intervention. Prices were almost always substantially above the competitive level (although they did not rise all the way up to the monopoly price), and quickly returned to a supra-competitive state even when they were externally forced to be competitive (the "shock" in the diagram below).[98] The observed pattern is very much consistent with that predicted by theoretical economic analysis of coordination between rational agents; and the findings are remarkably robust to variations and extensions.[99] Most importantly, the

Econ. Affairs, Rsch. Paper, 2020) (finding that the scale of learning required makes the adoption of learning algorithms unattractive commercially).

95. Gal, *supra* note 38, at 20–21. Accordingly, such a coordination-breaking effect might, be part of the analysis of the costs and benefits of personalized pricing.

96. *See* Ezrachi & Stucke, *Tacit Collusion*, *supra* note 15, at 228–29.

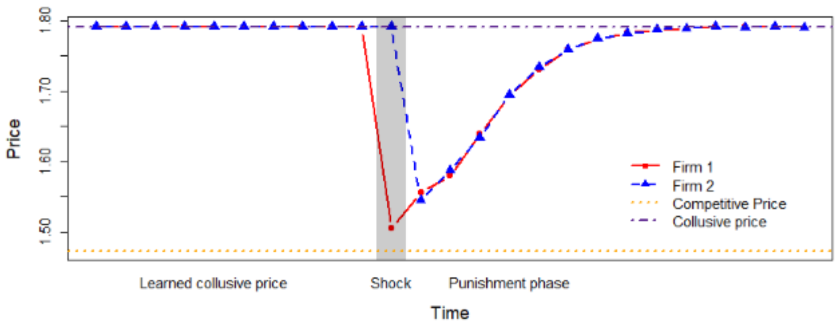
97. Calvano et al., *Protecting Consumers*, *supra* note 17, at 1041. For earlier work, see BRUNO SALCEDO, PRICING ALGORITHMS AND TACIT COLLUSION (2015), https://brunosalcedo.com/docs/collusion.pdf. For work on prediction algorithms, see, e.g., Jeanine Miklós-Thal & Catherine Tucker, *Collusion by Algorithm: Does Better Demand Prediction Facilitate Coordination Between Sellers?*, 65 MANAGEMENT SCI. 1552 (2019).

98. Calvano et al., *Protecting Consumers*, *supra* note 17, at 1041–42.

99. In a follow-up study, Calvano et al. also showed that algorithmic collusion can cope with more complex economic environments with imperfect information and imperfect monitoring. In general, their findings established that algorithmic collusion is not the product

algorithms did not condition their strategy on rivals' commitment to stick to the supra-competitive equilibrium, and did not communicate directly. Some limitations include the fact that it took the algorithms a relatively long time to learn to collude, yet this work provides proof of concept of the claim that learning algorithms can learn to collude.

Table 1: Price levels set by the algorithms (Calvano et al.)



Other simulation studies also show that algorithms are capable of coordinating in fabricated environments. For example, Klein et al. show that Q-learning algorithms in a sequential price-setting environment maintain a supra-competitive price level.[100] Q-learning algorithms do not necessarily scale well to more complex environments.[101] Hettich employed more powerful pricing algorithms using deep Q networks to simulate interactions in larger markets, and showed that under these conditions, high prices are reached much faster.[102] Malte employed another type of artificial intelligence, linear function approximation.[103] He found that the algorithms sustained supra-

of a fortuitous choice of parameters and prevails over a very broad range. Emilio Calvano, Giacomo Calzolari, Vincenzo Denicolò & Sergio Pastorello, *Algorithmic Collusion with Imperfect Monitoring*, 79 INT'L J. INDUS. ORG. 79 (2021).

100. Timo Klein, *Autonomous Algorithmic Collusion: Q-Learning Under Sequential Pricing* (Amsterdam Ctr. For L. & Econ., Working Paper No. 2018-15, 2020).

101. Ittoo & Petit, *supra* note 59, at 255. Yet previous learning was able to reduce the learning time to one tenth of its original interactions. Calvano et al., *Artificial Intelligence*, *supra* note 17, at 3300; *see also* Asker et al., *supra* note 54, at 456 (finding that even without dictating the algorithm's strategy, programmers may bias the algorithm's learning process towards coordination).

102. Matthias Hettich, *Algorithmic Collusion: Insights from Deep Learning* (2021), https://ssrn.com/abstract=3785966.

103. Jeschonneck Malte, *Collusion among autonomous pricing algorithms utilizing function approximation methods* (Heinrich Heine Univ. Düsseldorf, DICE Discussion Paper No. 370, 2021).

competitive prices, but tended to be exploitable by deviating agents in the short term, a fact we shall return to in one of the proposed solutions.

Empirical evidence showing that algorithms can learn to coordinate in practice is also beginning to accumulate. In seminal research, Assad, Clark, Ershov and Xu studied the effects of pricing algorithms in the German retail gasoline market. They found that prices were not affected when algorithmic pricing was adopted by either a monopolist, or by only one of the two firms in a duopoly market, but increased substantially (9–28%) after both firms in a duopoly switched from manual to algorithmic pricing.[104] These results suggest that algorithmic pricing raised margins through its effects on competition.[105] They also found that the impact increases with time, which is suggestive of autonomous learning.[106] Although the evidence was indirect (as the researchers inferred from other data when the algorithms started to operate), the findings are consistent with experimental results as well as with canonical economic models of coordination.[107]

The importance of such theoretical, experimental and empirical studies cannot be overstated. Together, they compel an undeniable and credible conclusion: under some market circumstances, pricing algorithms can achieve coordination at supra-competitive prices without any human intervention or prior agreement. Moreover, while it is important to study algorithmic coordination under wider and more challenging sets of market conditions (e.g., more players, more dynamic demand, multi-sided markets), there is good reason to believe that pricing algorithms will only get better at their tasks as technology continues to improve.[108] Accordingly, the threat to consumers is no longer science fiction. We now turn to the legality of autonomous algorithmic coordination.

III. ALGORITHMIC COORDINATION IS NOT ILLEGAL

> [N]ot all algorithms will have been to law school. So maybe there [are] a few out there who may get the idea that they should collude with another algorithm.[109]

Assume that the algorithm's code includes a compliance goal: "Never breach antitrust law." Would this remove the negative welfare effects created

104. Assad et al., *supra* note 9, at 5.

105. *Id.*, at 41–42.

106. Calvano et al., *Protecting Consumers*, *supra* note 17, at 1041.

107. Assad et al., *supra* note 9, at 42–43.

108. Algorithms also make it easier for colluders to engage in price discrimination. We leave the implications of this for future study.

109. Margrethe Vestager, EU Comm'r, Speech on Algorithms and Competition at the Bundeskartellamt 18th Conference on Competition, Berlin (Mar. 16, 2017).

by algorithmic coordination, based on mutual dependence in pricing, which occurs without human intervention, oversight, or even knowledge, and without communication? The answer is no.[110] This is because antitrust prohibitions of coordinated conduct are conditioned on the existence of "an agreement in restraint of trade." This has been interpreted as the offer and acceptance of an agreement not to compete.[111] Accordingly, pure oligopolistic coordination is not captured under the law, even though its effects on consumers are similar to those of an illegal cartel.[112] As Picht and Freund suggest, this focus on the mode of communication may be partly explained by the traditional assumption that coordination without prior agreement is not very common, given that in most industries complicating factors exist[113]—along with the difficulties in remedying pure oligopolistic coordination, and a fairness argument based on the fact that firms are simply reacting to market conditions, much like firms in competitive markets, as elaborated below.[114] Algorithmic coordination, which is based on similar conduct, is therefore also legal, despite the fact that it may become more common.

This is not to say that antitrust cannot capture any type of conduct which leads to algorithmic coordination. Antitrust laws can limit some actions which alter market conditions in a way that enables algorithmic coordination.[115] In particular, as I have suggested elsewhere, the legal prohibition of "plus factors"—intended and avoidable acts that facilitate coordination by creating conscious commitments to a common scheme, and are not justified on

110. *See, e.g.*, Gal, *supra* note 38, at 97–114 (arguing that oligopolisic coordination engaged in by algorithms does not infringe antitrust laws unless it constitutes a facilitating practice); Joseph E. Harrington, *Developing Competition Law for Collusion by Autonomous Artificial Agents*, 14 J. COMPETITION L. ECON. 331, 331 (2018).

111. Louis Kaplow, *On the Meaning of Horizontal Agreements in Competition Law*, 99 CALIF. L. REV. 683 (2011). Carlton et al. suggest that it can be difficult to define agreement when examining conduct among economic agents when no express communication has occurred. Carlton et al., *supra* note 73, at 424.

112. Theatre Enter. Inc. v. Paramount Film Distrib. Corp., 346 U.S. 537, 541 (1954) ("[T]his Court has never held that proof of parallel business behavior conclusively establishes agreement or, phrased differently, that such behavior itself constitutes a Sherman Act offense."); *see also* E.I. Dupont de Nemours & Co. v. FTC, 729 F.2d 128, 139 (2d Cir. 1984) ("The mere existence of an oligopolistic market structure in which a small group of manufacturers engage in consciously parallel pricing of an identical product does not violate the antitrust laws.").

113. In the U.S. context, *see, e.g.,* David Scheffman, *Commentary on 'Oligopoly Power, Coordination and Conscious Parallelism,' in* NEW DEVELOPMENTS IN THE ANALYSIS OF MARKET STRUCTURE 295 (Joseph Stiglitz & Frank Mathewson eds. 1986).

114. Picht & Freund, *supra* note 68, at 6.

115. For elaboration of such arguments, see, e.g., Axel Gautier, Ashwin Ittoo & Pieter Van Cleynenbreugel, *AI Algorithms, Price Discrimination and Collusion: A Technological, Economic and Legal Perspective*, 50 EUR. J. OF L. & ECON. 405, 429–30 (2020).

procompetitive grounds—can be applied to limit the ability of algorithms to coordinate.[116] Acts that raise red flags may include, inter alia, making it easier for competitors to observe one's algorithms and/or databases; [117] or technologically "locking" one's algorithm so that it is difficult to change, thereby increasing the commitment to the pricing scheme embedded in it. These acts could be plus factors, in that they may facilitate coordinated conduct; they are potentially avoidable; and they are unlikely to be necessary in order to achieve procompetitive results. Such practices may thus amount to "coordination by design," and should trigger a deeper investigation into procompetitive justifications. The remedy is clear and easy to apply: prohibiting the act of concern. Yet such prohibitions do not capture the hardcore case of autonomous algorithmic coordination.[118]

Some scholars suggest taking the principle of plus factors one step further. Thomas defines collusion as requiring only the presence of parallel informational signals which achieve a supra-competitive equilibrium. [119] Donini et al. suggest that the mere use of signaling algorithms should fall under the prohibition, even absent an anti-competitive intent.[120] Yet, while some forms of signaling might be considered a facilitating practice under some market conditions, it must be remembered that setting one's prices in a way which accounts for the expected reaction of one's rivals is the very definition of legal oligopolistic coordination. For the same reason, current prohibitions do not capture instances in which firms engage in a pattern of successive price increases, which amounts to repeated parallel pricing;[121] nor will it work to simply shift the burden of proof.[122] Indeed, similar suggestions were made by Posner several decades ago,[123] and were refuted by courts and antitrust

116. Gal, *supra* note 38, at 99–105, 110–15.

117. Interestingly, some laws relating to artificial intelligence require the transparency of the algorithm, in order to ensure that its decisions comply with other legal requirements (such as non-discrimination based on certain criteria, or content moderation that does not infringe freedom of speech). These laws might sometime inadvertently strengthen coordination, but legally mandating transparency to all. One potential solution to this clash is to limit transparency to rivals, while maintaining transparency towards enforcers.

118. *Id.* at 113–14.

119. Stefan Thomas, *Harmful Signals: Cartel Prohibition and Oligopoly Theory in the Age of Machine Learning* 15 J. COMP. L. & ECON. 159 (2019).

120. DONINI, *supra* note 3, at 109.

121. Alan Devlin, *A Proposed Solution to the Problem of Parallel Pricing in Oligopolistic Markets*, 59 STAN. L. REV. 1111, 1144 (2007) (suggesting an amendment of the law to capture instances such as repeated instances of price leadership).

122. *See* Bernhardt & Dewenter, *supra* note 30, at 82–83 (writing that the German Monopolies Commission recommends a comprehensive monitoring of markets before shifting the burden of proof).

123. RICHARD A. POSNER, ANTITRUST LAW: AN ECONOMIC PERSPECTIVE 146 (1976); Richard A. Posner, *Oligopoly and the Antitrust Laws: A Suggested Approach*, 21 STAN. L. REV. 1562,

agencies.[124] While it might be time to rethink such policies, and to more finely differentiate between different methods of reaching oligopolistic coordination, the law as it stands went down a different path.[125]

Another potential option is treating algorithmic coordination as a joint monopoly.[126] The firms operating the algorithms would then be subject to the legal restrictions imposed on monopolies. However, even if a joint monopoly can be proven, a rare event, it must still be shown that the algorithms monopolized their power. Yet algorithmic coordination does not generally involve exclusionary conduct, and high prices are not prohibited, as such.[127]

All of this raises a significant problem. As noted in the recent article in *Science*, "the increasing delegation of price-setting to algorithms has the potential for opening a back door through which firms could collude lawfully."[128] Indeed, as the use of sophisticated learning algorithms becomes more commonplace, more markets may move from collusion to coordination. And while both lead to supra-competitive prices, only the former is currently prohibited by our laws.

IV. LIMITATIONS OF EXISTING AND CURRENTLY PROPOSED SOLUTIONS

The increased potential for algorithmic coordination has generated a burgeoning literature suggesting innovative solutions. The benefits and limitations of the main suggestions made so far are briefly analyzed. The analysis relies on two basic assumptions. First, pricing algorithms may also

1562 (1969) [hereinafter Posner, *Oligopoly*]. Posner later repudiated his view. Richard A. Posner, *Review of Kaplow*, *Competition Policy and Price Fixing*, 79 ANTITRUST L.J. 761, 767 (2014) [hereinafter Posner, *Review*] (arguing that the efficacy of prohibiting oligopolistic coordination is also dependent on chilling effects: "any remedy for tacit collusion is likely to impose social costs . . . . I don't think one can have any confidence that punishing tacit colluders under antitrust law can produce net social benefits"). For criticism of the focus on agreement, see also Carlton et al., *supra* note 73 at 424 ("[A]ttempts to determine the legality of many forms of communication by assessing whether or not they conform to some connotation of the word "agreement" are inappropriate.").

124. Bell Atlantic Corp. v. Twombly, 550 U.S. 544 (2007).

125. Another problem involves the intent requirement, if the developer or user did not foresee the coordination, since some degree of human involvement is required to establish a causal link that can justify the imposition of liability. *See, e.g.*, Nicolo Zingales, *Antitrust Intent in an Age of Algorithmic Nudging*, 7 J. ANT. ENF. 386 (2019). This issue, which might require a fundamental change in our thinking, is beyond the scope of this article.

126. Karsten T. Hansen, Misra Kanishka & Mallesh M. Pai, *Frontiers: Algorithmic Collusion: Supra-Competitive Prices via Independent Algorithms*, 40 MKTG. SCI. 1 (2021).

127. Verizon Commc'ns, Inc. v Law Offs. of Curtis V. Trinko, LLP, 540 U.S. 398 (2004).

128. Calvano et al., *Protecting Consumers*, *supra* note 17; *See also* EZRACHI & STUCKE, *supra* note 14, at 39; Mehra, *supra* note 15; OECD, *supra* note 10.

yield benefits, for example by enhancing productive efficiency. Second, any legal rule should be reasonably easy to understand and follow.

A. PER SE ILLEGALITY

Some scholars suggest that algorithmic pricing should remain free from regulatory intervention, raising two lines of argument in support of this view. The first holds that algorithmic coordination is largely a speculative scenario, unlikely to be found in real-world markets. Schrepel, for example, contends that algorithmic coordination is fundamentally unimportant for antitrust, given the lack of conclusive empirical studies on the matter.[129] Yet, as elaborated above, in recent years empirical as well as experimental evidence has accumulated to make a strong case for the existence of algorithmic coordination under some market conditions. A related argument is that the lack of real-world cases brought against pricing algorithms indicates that this problem is not significant.[130] Yet if algorithmic coordination is legal, why should we expect cases? Furthermore, an absence of evidence does not equate to evidence of absence.[131] Moreover, even if at least some of the repricing software currently sold in markets is not sufficiently sophisticated to facilitate coordination,[132] this is not necessarily indicatory of the long-term status quo. Rather, it is in the interest of suppliers to seek more sophisticated software that would increase their profits.

Another line of argument holds that regulatory intervention will prevent firms from enjoying the benefits of using pricing algorithms, which could then translate into benefits to consumers, and that the costs of false positives from such intervention outweigh the costs of false negatives from not intervening (and thus allowing coordination to occur).[133] Others add that limiting the use of such algorithms will only serve to strengthen large firms, given that the loss of cost advantages associated with automated repricing might harm small firms more than large ones.[134] These claims depend on the efficiency of algorithms and the available regulatory tools, and cannot be evaluated in the abstract.

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129. Thibault Schrepel, *The Fundamental Unimportance of Algorithmic Collusion for Antitrust Law*, HARV. J. L. & TECH. (Feb. 7, 2020), https://jolt.law.harvard.edu/digest/the-fundamental-unimportance-of-algorithmic-collusion-for-antitrust-law.

130. *Id.*

131. Malte, *supra* note 103, at 34.

132. Vito Stefano Bramante, Emilio Calvano, Giacomo Calzolari & Maximilian Schaefer, *Algorithms in the Wild: Experimental Evidence from an Online Marketplace*, EODS RSCH. SYMP. (2022).

133. DONINI, *supra* note 3, at 90; Stewart-Moreno, *supra* note 60, at 67.

134. Maciej Hulicki, *Algorithm Transparency as a Sine Qua Non Prerequisite for a Sustainable Competition in a Digital Market?*, 6 EU & COMPAR. L. ISSUES & CHALLENGES SERIES, 238, 249–50 (2021).

An opposite suggestion can also be raised, that pricing algorithms should be banned altogether. Yet any remedy must not disregard the fact that such algorithms also yield benefits. Given that research on algorithmic pricing is still in its early stages, regulators should move cautiously.

B. DEVELOPMENT OF DETECTION TOOLS

Many scholars suggest that regulatory efforts should be concentrated on the development of better detection tools, which would alert authorities to instances of coordination and thus serve as "intervention triggers," to indicate when coordination is taking place.[135] To achieve this, antitrust authorities could employ computer and data scientists who are skilled in demystifying algorithms and analyzing the operation of pricing algorithms, a suggestion which has already been adopted in jurisdictions such as Australia and Britain.[136] Agencies could also deploy algorithms that automatically monitor markets to detect coordinated conduct in real time, analyzing price changes as well as changes in market conditions that may facilitate coordination.[137]

Another strand of such proposals focuses on transparency. Some scholars suggest requiring transparency in the design of algorithms, and in the data which is inputted into them, in order to enable external observers to understand their decision-making processes.[138] Others suggest mandating explainability of the considerations that led to a specific pricing decision. Proposals vary. For example, firms could be required to establish mechanisms that facilitate audits of artificial intelligence (AI) systems, such as logging all the system's processes and outcomes to ensure traceability.[139] Other proposals

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135. MASSIMO MOTTA & MARTIN PEITZ, INTERVENTION TRIGGERS AND UNDERLYING THEORIES OF HARM 43 (2020), https://ec.europa.eu/competition-policy/system/files/2021-03/kd0420575enn.pdf; Beneke & Mackenrodt, *supra* note 28, at 119–21; Giuseppe Colangelo, *Artificial Intelligence and Anticompetitive Collusion: From the 'Meeting of Minds' Towards the 'Meeting of Algorithms'?* 12 (TTLF Stan. L. School, Working Paper 74, 2021); DONINI, *supra* note 3, at 99–100; Bernhardt & Dewenter, *supra* note 30, at 331–32.

136. Bernhardt & Dewenter, *supra* note 30, at 331–32; *see also* Thibault Schrepel & Teodora Groza, *The Adoption of Computational Antitrust by Agencies: 2021 Report*, 2 STAN. COMPUTATIONAL ANTITRUST 78 (2022).

137. LÖFSTRÖM ET AL., *supra* note 1, at 24–25; DONINI, *supra* note 3, at 116–18; Nikita Koradia, Kiran Manokaran & Zara Saeed, *Algorithmic Collusion and Indian Competition Act: Suggestions to Tackle Inadequacies and Naivety*, *in* THE DIGITAL ECONOMY AND COMPETITION LAW IN ASIA 186–87 (Steven Van Uytsel ed., 2021); Bernhardt & Dewenter, *supra* note 30, at 332; Foo Yun Chee, *EU Considers Using Algorithms to Detect Anti-Competitive Acts*, REUTERS (May 4, 2018), https://uk.reuters.com/article/us-eu-antitrust-algorithm/eu-considersusing-algorithms-to-detect-anti-competitive-acts-idUKKBN1I5198.

138. Bernhardt & Dewenter, *supra* note 30, at 335; Hulicki, *supra* note 134, at 251–55; Koradia et al., *supra* note 137, at 184–85.

139. EUR. COMM'N, HIGH-LEVEL EXPERT GROUP ON ARTIFICIAL INTELLIGENCE, ASSESSMENT LIST FOR TRUSTWORTHY ARTIFICIAL INTELLIGENCE (ALTAI) FOR SELF-

go further, suggesting mandatory adoption of "white box algorithms"—algorithms designed such that their actions, decisions, and relationships between variables and outputs are observable and interpretable.[140]

Algorithmic transparency and explainability make it easier to investigate coordination. Such investigations are highly important, as they may enable authorities both to determine the extent of coordination, and to learn more about the market dynamics which enable it.[141] Yet analyzing algorithms is complicated, and demands a high degree of expertise.[142] Algorithmic transparency may also need to be balanced with the protection of trade secrets and privacy considerations, should the data also need to be examined.[143] Furthermore, explainability implies significant intervention in the market. For example, it would prevent firms from using deep learning algorithms, which might be more efficient and capable of generating innovative pricing schemes, but which are inherently not transparent.[144] Transparency could even facilitate coordination:[145] a competitor facing a transparent algorithm might need zero rounds to create coordination, because he can "read its mind" before reacting. But most importantly, simply observing algorithmic coordination does not change its legal status.

C. PROCESS-BASED PROHIBITIONS: REGULATING THE DESIGN OF THE ALGORITHM

The outcome of an algorithm is affected by the data inputted into it, as well as the analysis performed on such data. Accordingly, both can theoretically be regulated, to affect the algorithm's decision-making. Several such solutions are explored below.

Some commentators suggest changing the law to be process-based (i.e., regulating the process or mechanism that leads to coordination), rather than

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ASSESSMENT (2020), https://digital-strategy.ec.europa.eu/en/library/assessment-list-trustworthy-artificial-intelligence-altai-self-assessment; Hulicki, *supra* note 134, at 241.

140. Beneke & Mackenrodt, *supra* note 28.

141. *Id.* at 99–100; Koradia et al., *supra* note 137, at 187.

142. Hulicki, *supra* note 134.

143. Bamberger et al. argue that such "verification dilemmas," which must balance between opportunities that require the verification of some facts, and risks of exposing sensitive information in order to perform verification, can at least be partly overcome by zero-knowledge proofs (ZKPs)—a class of cryptographic protocols that allow one party to verify a fact or characteristic of secret information without revealing the actual secret. Kenneth A. Bamberger, Ran Canetti, Shafi Goldwasser, Rebecca Wexler & Evan J. Zimmerman, *Verification Dilemmas in Law and the Promise of Zero-Knowledge Proofs*, 37 BERKELEY TECH. L.J. 101 (2021).

144. Bernhardt & Dewenter, *supra* note 30, at 335.

145. Hulicki, *supra* note 134, at 249–56; Ilgin Isgenc, *Competition Law in the AI ERA: Algorithmic Collusion under EU Competition*, 24 TRINITY C.L. REV. 35, 48 (2021).

focusing on the existence of an agreement or communication between the parties.[146] Calvano et al., for example, suggest shifting the regulatory focus from communication to the coordinating pricing rules learned by the algorithm. In other words, they suggest prohibiting the use of pricing mechanisms (whole algorithms or parts thereof), which can be clearly shown to produce a predictable coordinated outcome, while ensuring that the efficiency gains from using such algorithms are not lost. To ensure that only non-coordinating algorithms are employed, they suggest that each algorithm would be subject to approval by a regulator prior to use, to verify that it is not likely to produce a coordinated outcome.[147]

The advantages of this solution are manifold. In part, they derive from the differences between human and algorithmic coordination. First, given that algorithms exist outside the mind of the individuals responsible for setting prices, they can be audited to determine what led to coordination (correlations, even if causality is not explained), thereby limiting the need to focus on communication.[148] Furthermore, the fact that a pricing algorithm is involved, and its input can be observed and regulated, enables the regulator to ensure that prices can be posted for consumers, but not (directly) observed by the algorithm. Second, the algorithm's reactions to different market conditions can be tested before it is put to use.[149] Accordingly, the algorithm's latent rules of conduct may be uncovered and regulated. Figure 1 (reproduced from Calvano et al.) depicts these differences between humans and algorithms in the processes that lead to price coordination.

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146. Focus on economic effects, rather than on communication, was also suggested in the non-algorithmic context. *See*, *e.g.*, LOUIS KAPLOW, COMPETITION POLICY AND PRICE FIXING (2013). It was previously suggested by Posner. *See* Posner, *Oligopoly*, supra note 123, at 1562 (1969). Posner later changed his mind. *See* Richard Posner, *Review of Kaplow, Competition Policy and Price Fixing*, 79 ANTITRUST L.J. 761 (2014) (writing a subsequent article after having "second thoughts" about his original proposal.).

147. Calvano et al., *Protecting Consumers*, *supra* note 17, at 1041; *see also* Calvano et al., *supra* note 40, at 169; DONINI, *supra* note 3, at 98–99.

148. Calvano et al., *Protecting Consumers*, *supra* note 17, at 1041.

149. *Id.*; Gal, *supra* note 38.

Figure 1: Differences between humans and algorithms in the processes that lead to price coordination (Calvano et al., 2020)[150]

The process that produces higher prices

	COMMUNICATIONS	COLLUSIVE PRICING RULES	HIGHER PRICES
Humans	Present, discoverable	Latent, not discoverable	Observable, difficult to evaluate
Algorithms	Not present	Latent, discoverable	Observable, difficult to evaluate

More importantly, the suggested solution goes to the root of the problem—to the conduct which facilitates coordination. Indeed, some economic studies of algorithmic coordination point to potential changes in pricing algorithms that can restore a more competitive outcome. For example, Calvano et al. show that algorithms learn to price competitively if they are memoryless (i.e., they cannot remember past prices) or short-sighted (i.e., they do not value future profits).[151] Another potential benefit of such a solution is that it may be applied ex ante, by mandating that designers and users of algorithms include internal limitations that prevent coordinated outcomes (competition-by-design).[152]

In line with this proposal, other scholars have suggested specific process-centric limitations on pricing algorithms. Some suggestions relate to the data inputted into the algorithm. These include, for example, prohibiting the use of data which relates to prices set by rivals,[153] or restricting the storage of recent data on other firms' prices.[154] Other suggestions relate to the decisional process itself. For example, altering the code to include a (theoretical) threat of new entry,[155] or only permitting the use of algorithms that cannot react to data that

150. Calvano et al., *Protecting Consumers*, *supra* note 17, at 1040–41.

151. Calvano et al., *Artificial Intelligence*, *supra* note 17, at 3280.

152. *See, e.g.*, Gautier et al., *supra* note 115, at 429–30.

153. Brown & MacKay, *supra* note 4, at 45; Brendan Ballou, *The 'No Collusion' Rule*, 32 STAN. L. & POL'Y REV. 213, 248 (2021).

154. Ballou, *supra* note 153, at 248.

155. DONINI, *supra* note 3, at 110–14.

might lead to anti-competitive conduct.[156] To enable such regulation, the algorithm's code must be easily readable and understandable.[157]

Klein and Gaban suggest that compliance with such regulation can be aided by specialist private firms.[158] Indeed, RegTech firms already offer a multitude of services designed to build compliance into algorithms.[159] Aiscension, for example, is an AI-based service designed to limit the possibility of infringement of antitrust laws and the costs of internal reviews.[160] Algorithms that employ such services can potentially maximize a firm's profit while ensuring that it is not done through coordination.[161]

In theory, these suggestions resolve the predicament posed by algorithmic coordination in an elegant way. Yet three main problems arise. The first is legal: under current law, recognizing coordination is insufficient for preventing it.[162] Calvano et al. suggest making the pricing rules that result in coordination unlawful under Section 5 of the Federal Trade Commission Act.[163] Indeed, as Posner famously argued, oligopolistic coordination has elements of offer and acceptance, and thus can theoretically satisfy the requirements for an agreement.[164] Yet overcoming decades of case law that makes oligopolistic coordination legal—is a tall order. A change in the law might be required. Yet the law is a heavy ship, which does not easily change its course.

The second problem is identification: identifying the pricing rules that lead to coordination and distinguishing them from other parts of the code. In order to prohibit a certain conduct, the law must be clear on what exactly is prohibited and what firms are allowed to do. Calvano et al. suggest that antitrust authorities experiment in the lab to determine which pricing rules

156. *Id.* at 111; Schwalbe, *supra* note 46, at 599; *see also* Miklos-Thal & Tucker, *supra* note 97 (addressing the impact on market outcomes of algorithms that are "hard-coded," meaning they have no ability to explore and learn via market interactions).

157. DONINI, *supra* note 3, at 112 (suggesting that this might require tools that create explainability in human language, rather than machine code).

158. Vinicius Klein & Eduardo Molan Gaban, A New Language for AI and the Legal Discourse, 20 (2021) (unpublished article), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3927985.

159. *Id.* at 15, 18.

160. DLA PIPER, https://www.dlapiper.com/en/europe/focus/aiscension/overview/ (last visited Feb. 9, 2022).

161. Klein & Gaban, *supra* note 144, at 18–19.

162. *See, e.g.*, Gal, *supra* note 38, at 97–114 (arguing that oligopolisic coordination engaged in by algorithms does not infringe antitrust laws unless it constitutes a facilitating practice); Joseph E. Harrington, *Developing Competition Law for Collusion by Autonomous Artificial Agents*, 14 J. Competition L. Econ. 331, 331 (2018).

163. Calvano et al., *Protecting Consumers*, *supra* note 17, at 1042.

164. POSNER, *supra* note 123, at 1081.

might lead to coordination.[165] Yet such experiments often depend on the environment in which the algorithm is tested. Significant challenges thus arise regarding the market conditions authorities should take into account when testing the algorithm. To name a few, should the number of rivals and the degree of product differentiation be based on current, foreseeable, or theoretical circumstances? What is the relevant time frame—a question which might be especially relevant when algorithms need time to learn and devise their own strategies? What assumptions should be made with regard to the decision-making of one's rivals, especially when using different types of algorithms may lead to different outcomes? To the degree that these conditions determine the outcome, a large number of settings might need to be tested a priori, or regulators might need to monitor changes in market conditions and test the algorithm repeatedly. These monitoring issues are exacerbated by the fact that, as Assad et al. emphasized, there is no standard format by which algorithms operate. Instead, they are often customized for a specific information technology setting and for a particular problem faced by a firm.[166] Furthermore, especially when learning algorithms are employed, any monitoring scheme would require continuous adaptation to the latest algorithmic technology.[167] All of this would be resource-intensive and raise issues of competence. But even if all these issues could be overcome, unless all assumptions are clear ex ante, it would be difficult to create certainty for firms investing in algorithms. Indeed, as algorithms or market conditions change, the decision-maker must also be able to change his decision of whether the use of a certain algorithm is allowed or not. But if such changes are not known ahead of time, this might limit the ability of firms to make long-term investments in their algorithms, in fear that, one day, their use will be prohibited. For the same reason, self-regulation is not necessarily a straightforward, efficient solution. In addition, in some cases it might be impossible to identify and separate the relevant part of the code from the rest of the algorithm, such as if a deep learning algorithm devises a new strategy for maximizing profits, which leads to coordination. The whole algorithm would need to be prohibited.

The third problem, which focuses on the remedy, is more fundamental and difficult to fix. Assume that we succeed in identifying that part of an algorithm's code that leads to coordination. How do we ensure that prohibiting its use necessarily leads to increased welfare, and that the efficiency gains from using such algorithms are not lost? This is especially true, as noted above, in that proscribing only the problematic bit of code may be impossible, implying

165. Calvano et al., *Protecting Consumers*, *supra* note 17, at 1042.

166. Assad et al., *supra* note 9, at 47.

167. Bernhardt & Dewenter, *supra* note 30, at 83–84.

that the use of learning algorithms might have to be prohibited altogether. The efficiency of such a prohibition poses a big challenge, which goes to the core of what we know about market dynamics. Given the importance of this challenge, it is elaborated below.

Proposals for regulatory intervention in algorithmic code raise similar issues to those that led antitrust authorities around the world not to regulate oligopolistic coordination, even though it can theoretically meet the "agreement" requirement. This decision was based on three main factors.[168] First, firms in all markets, including competitive ones, determine their prices based on market conditions, including prices set by their rivals and rivals' foreseeable reactions to their own price changes. It is thus not fair, the argument goes, to prevent oligopolists from setting their prices in the same way.[169] Another way to understand this argument is that, in relation to the ways firms react to market conditions, coordination is indistinguishable from conduct of firms in competitive markets. Thus, while a cartelistic agreement is an artificial interference in market conditions, oligopolistic coordination is a natural reaction to market conditions. Yet, in my view, the fairness argument can be countered on a normative level: if similar conduct under different market scenarios lead to different effects on social welfare, and we can clearly differentiate between the different scenarios, then the fact that the conduct is similar, by itself, does not mandate similar legal reaction. In fact, our monopoly prohibitions may prohibit conduct, engaged in by a monopoly, that would have been legal if engaged in by a firm in a competitive market. The second reason is that, as noted above, oligopolistic coordination was seen by some economists as a rare occurrence.[170] This may no longer be the case.

The third reason is the most challenging, and focuses on the difficulty of fashioning a suitable remedy.[171] Specifically, the regulator would have to determine what weight, if any, firms should be allowed to give different factors, such as the prices set by rivals, in their decision-making. As suggested by Justice (then judge) Breyer, oligopolistic coordination does not constitute an offense, "not because such pricing is desirable (it is not), but because it is close

168. *See* Donald F. Turner, *The Definition of Agreement Under the Sherman Act: Conscious Parallelism and Refusals to Deal*, 75 HARV. L. REV. 655, 671 (1962) [hereinafter Turner, *The Definition*]; Donald F. Turner, *The Scope of Antitrust and Other Economic Regulatory Policies*, 82 HARV. L. REV. 1207, 1231 (1969) [hereinafter Turner, *The Scope*].

169. Turner, *The Definition*, *supra* note 168, at 671; Turner, *The Scope*, *supra* note 168, at 1231.

170. *See generally* Scheffman, *supra* note 113.

171. *See, e.g.*, Posner, *Review*, *supra* note 123, at 765 ("remedy . . . is the principal problem presented by proposals to make [oligopolistic coordination] illegal"); Gregory J. Werden, *Economic Evidence on the Existence of Collusion: Reconciling Antitrust Law with Oligopoly Theory*, 71 ANTITRUST L.J. 719 (2004).

to impossible to devise a judicially enforceable remedy for 'interdependent' pricing. How does one order a firm to set its prices without regard to the likely reactions of its competitors?"[172] Posner makes a similar claim:

> A seller must decide on a price. But if tacit collusion is forbidden, how does a seller in a market in which conditions (such as few sellers, many buyers, and a homogeneous product) favor convergence by the sellers on a joint maximizing price, and adherence to that price, decide what price to charge? If he charges the joint maximizing price (and his "competitors" do as well), and tacit collusion is illegal, he is in trouble. But how is he to avoid getting into that trouble? Would he have to adopt cost-plus pricing? That would be a safe harbor, but would be the equivalent of subjection of the firm to old-fashioned public utility/common carrier rate regulation, which has been discredited, and would require a total institutional makeover of antitrust law.[173]

Such intervention in market dynamics would only be justified if it would lead to an efficient market equilibrium, one that increases consumer welfare while accounting for not only static effects but also long-term dynamic effects. Economic theory, however, does not supply good answers as to how much weight should be given to rivals' prices or pricing behavior in order to set a price that is optimal for long-term consumer welfare. All agree that the pricing rule should create sufficient incentives for productive and dynamic efficiency, but conditions for optimal investments have been debated for decades with no clear answer.[174] Moreover, existing studies assume that firms can and will react to prices set by their rivals—a condition which no longer holds once we limit the ability of algorithms to react to prices set by their rivals. Accordingly, the long-term dynamic effects of such an intervention on productive and dynamic efficiency are yet to be studied. Furthermore, to ensure that consumer welfare is not harmed, the quality and quantity of both the product and the level of service provided would have to be monitored and potentially regulated, and not just price. We explore several examples of this challenge below.

Assume a simple mutual interdependence in pricing: each firm realizes it cannot steal enough consumers from its rival before it can respond, and the rival will respond because it is more profitable to match the price cut and share the market at a lower price than to permit the price-cutting rival to steal market share. Each would not cut price in the first instance. Cooperative pricing is

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172. Clamp-All Corp. v. Cast Iron Soil Pipe Institute, 851 F.2d 478, 484 (1st Cir. 1988).

173. Posner, *Review*, *supra* note 123, at 763.

174. *See generally* RICHARD J. GILBERT, INNOVATION MATTERS: COMPETITION POLICY FOR THE HIGH-TECHNOLOGY ECONOMY (2020) (reviewing the state-of-the-art literature on conditions for innovation).

therefore a logical outcome of a market game without secret meetings or additional communication beyond price information, which is communicated to both rivals and consumers. In this setting, unilateral interest, by itself, leads to cooperative pricing, which is self-enforcing.[175]

Now, in order to prohibit such coordination, assume that we do not allow pricing algorithms to give any weight to rivals' prices. This might impede coordination by limiting firms' ability to send price signals that could then be followed by rivals. Yet there are alternatives that might still allow coordination, if the algorithm engages in trial-and-error strategy, testing profits under different pricing decisions, without directly observing prices. Indeed, as Posner acknowledged, to limit coordination algorithms may need to be insensitive to demand, since demand incorporates the effects of one's price on the prices of one's rivals and hence the demand for one's good.[176]

But more importantly, prices serve functions other than enabling coordination. They are a fundamental element in pricing decisions even under perfect or workable competition, as they affect the ability to respond to changes in cost and demand conditions, as well as incentives to enter and invest in oligopolistic markets.[177] Take, for example, a market where different firms offer differentiated products. Each firm sets its price (slightly) above competitive levels, depending, inter alia, on the prices set by rivals as well as the extent to which consumer demand to their products differs. Thus, price plays an important role in creating incentives for firms to invest in carving a niche for themselves by offering a product that some consumers would prefer (a situation known as monopolistic competition), even if they have limited overall market power. Or take a case where a firm is considering whether to make a large investment in a new and better product. Should its investment succeed, it hopes to cover its costs by pricing a bit higher than its rivals. Compelling the firm to disregard competitors' prices increases its uncertainty about whether its investment will be profitable. Or, a firm might think that a competitor has better insights into changes in market demand, which are reflected in its price changes.[178] Such prohibitions would remove an essential function of price information in markets, effectively forcing firms to operate while partially blindfolded.

This raises the question of how learning algorithms will perform in such fabricated environments, and how their performance would affect incentives for market entry and innovation. The problem is that economic theory has not

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175. Carlton et al., *supra*, note 73, at 428.

176. Posner, *Review*, *supra* note 123, at 765.

177. Carlton et al., *supra* note 73, at 429; United States v. Socony-Vacuum Oil Co., 310 U.S. 150, 224 (1940) ("Pricing dynamics are 'the central nervous system of the economy.'").

178. Posner, *Review*, *supra* note 123, at 764.

as of yet generated definite economic models determining which market conditions lead to oligopolistic coordination, and, relatedly, what is the role that the ability to react to other firms' prices plays in entry and investment decisions in such markets.[179] Furthermore, the knowledge that firms will not be able to react to prices of their rivals, may reduce entry into oligopolistic markets and lead to reductions in social welfare.[180] For similar reasons, such a prohibition might also reduce the incentives of firms to use otherwise beneficial pricing algorithms, unless human-facilitated oligopolistic coordination is also prohibited. As Posner suggests, another problem arises with regard to regulating passivity as an enabler of oligopolistic coordination—that is, when firms decide not to actively poach their rivals' consumers. Ordering firms to compete is very different from ordering them not to agree not to compete.[181]

The fact that rivals' prices serve an important function also refutes an argument offered by Calvano et al.—namely, that removing from an algorithm those parts of the code that lead to coordination can involves similar tasks such as constraining racial and gender bias by preventing the use of certain data.[182] The analogy is not complete.[183] This is because race and gender are not an integral part of the decision process when choosing who to employ or who is deserving of a loan. Indeed, taking race and gender out of the decision equation may arguably lead to more efficient decisions, benefiting both citizens and suppliers in the long run.[184] The same cannot be said for giving weight in one's pricing decisions to the prices (or trade terms) set by rivals, and the expected reaction of rivals to one's own changes in price.

Now assume that, in line with the above, algorithms are allowed to give some weight to the prices of others or to market reactions to their own prices. As noted above, the inability to directly detect rivals' price levels does not, by itself, limit the ability of the algorithm to react to changing market conditions, thereby reacting to prices indirectly. So the regulator might need to interfere further in the elements that determine the price. But, more fundamentally, how much weight should the algorithm be allowed to give to market reactions to its prices to create efficient long-term entry and investment incentives in

179. R. J. GILBERT, INNOVATION MATTERS: COMPETITION POLICY FOR THE HIGH-TECHNOLOGY ECONOMY (2020).

180. Carlton et al., *supra* note 73, at 429; Posner, *Review*, *supra* note 123, at 763 ("And might not entry into cartelized markets be deterred because an entrant who having successfully entered such a market charged the prevailing market price might be prosecuted as a tacit colluder?").

181. Posner, *Review*, *supra* note 123, at 763–64.

182. Calvano et al., *Protecting Consumers, supra* note 17, at 1042.

183. Posner, *Review, supra* note 123, at 763–64; *see also* Harrington, *supra* note 110.

184. *See, e.g.*, GARY BECKER, THE ECONOMICS OF DISCRIMINATION (2d ed. 1971).

oligopolistic markets? No economic theory provides clear answers. The ability to react to prices set by rivals creates both positive incentives (e.g., entry, investment), and negative effects (e.g., coordination), which are not easy to separate. Yet the court will need to determine the allowable parameters as well as how vigorously the firms must compete in order to avoid being found to have engaged in illegal oligopolistic coordination.[185] For example, should the algorithm's pricing be based on 50% reliance on the prices of rivals and 50% reliance on other factors (such as cost)—would this be deemed legal? Or—from a different perspective—how far from the most efficient supra-competitive oligopolistic price equilibrium should the algorithm set the price for it not to be considered illegal? That would require the regulator to determine, inter alia, under which conditions such a supra-competitive price should be calculated, as well as to neutralize any effects of potential differences in quality or monopolistic competition that affect the price. If the goal is to mandate that firms price products based on their own production costs, at competitive levels, then is it not better to simply make these the only parameters that can be taken into account? But such limitations suffer from all the known maladies of price regulation.[186] Furthermore, they require firms to base their prices on factors which might be difficult for them to calculate (for example, where several products supplied by the firm use the same internal service).[187]

The above discussion leads to the following observation: if we could assume that market participants as well as regulators have good tools to detect pure oligopolistic coordination, we might consider prohibiting firms from setting the maximal supra-competitive coordinated price, as well as a predetermined range of prices below it—a "red" collusive price zone into which firms would be prohibited from entering. As long as the prohibited price zone is not too wide, effects on entry and investment might not be strong, and consumer welfare might well be increased. Yet the assumption that we could differentiate pure price coordination from other reactions to market settings (including industry-wide upward pricing adjustments that react to changes in demand) is, at least currently, not practical.

While the discussion may increase our frustration with our inability to regulate oligopolistic coordination directly, we are not completely empty handed. In line with the discussion in Section III, while we do not have good remedial tools for limiting pure oligopolistic coordination, the same justification does not carry over to facilitating practices that enable the pricing

185. Posner, *Review*, *supra* note 123, at 764.

186. *See, e.g.*, EXCESSIVE PRICES AND COMPETITION LAW ENFORCEMENT (F. Jenny & Y. Katsoulacos eds., 2020).

187. *See id.*

algorithm to reach coordination faster, better, or in more cases, with no offsetting pro-competitive effects. For example, if the algorithm is taught coordination strategies, or is given focal points for coordination, in order to speed its learning, this should be prohibited. It is also time to explore how far the facilitating practices prohibition will carry, and potentially stretch its current limits. For example, exploring whether, if algorithms choose a focal point for coordination (such as a historical price or a delivered price) rather than simply reacting to market conditions, such conduct should amount to a facilitating practice.

While decentralized pricing may not work well in the algorithmic age, we still do not have a better tool for setting prices. Indeed, as shown, some traditional objections to limiting human oligopolistic coordination still carry weight in the age of algorithmic coordination. The only conditions which have changed is that it has become more prevalent, and equilibriums will be achieved faster, and become more stable.[188] As shown, even the increased ability to potentially interfere in the pricing process which leads pricing algorithms to engage in oligopolistic coordination, unfortunately does not reduce the frustration of antitrust with its inability to efficiently regulate oligopolistic coordination. In the absence of an ability to specify a superior alternative, it may be best not to interfere with the code, at least until we have better models of market conduct.

D. HARM-BASED PROHIBITIONS

Some scholars suggest replacing decisional rules based on agreement with harm-based prohibitions, focusing on the supra-competitive price itself.[189] Such rules can treat harm as a basis for illegal conduct. Alternatively, they can follow Turner's suggestion to apply forward-looking no-fault regulation.[190] Yet to create ex ante certainty, the regulator would have to determine what price is allowed, replicating the maladies of price regulation. Furthermore, for the reasons elaborated in the previous Section, the efficiency of market operations might be harmed.

E. EXTERNAL NUDGES

This category focuses on nudges that affect algorithmic coordination externally, creating internal incentives for a change of conduct without directly interfering with the design of the algorithm.[191]

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188. Bernhardt & Dewenter, *supra* note 30, at 329.

189. NICOLAS PETIT, SUBMISSION TO THE FTC HEARINGS ON COMPETITION AND CONSUMER PROTECTION IN THE 21ST CENTURY (2018).

190. Turner, *The Scope*, *supra* note 169, at 1231.

191. *Id.* at 165–67.

Beneke and Mackenrodt suggest imposing high fines on firms that engage in algorithmic coordination. Should the fine be sufficiently high, firms would have incentives to include in the algorithm's input variables the possibility of such a fine being imposed—thus reducing the likelihood of the algorithm's decision processes arriving at a supra-competitive price.[192] This suggestion has many benefits. Yet it is only relevant to illegal algorithmic cartels and not to legal algorithmic coordination. For the same reason, suggestions such as offering rewards for whistleblowers,[193] raising awareness,[194] extending liability to designers and suppliers of pricing algorithms,[195] or empowering consumer organizations to initiate sector inquiries,[196] do little to help prevent algorithmic coordination.

Johnson et al. have suggested an interesting nudge.[197] They explore ways that online retail marketplaces can mitigate price coordination between third-party merchants that might be achieved through algorithmic coordination. Their model attacks the foundations of coordination, by making deviation from a coordinated price both more attractive and harder for the other coordinating firms to punish. Specifically, the platform shows fewer options to consumers, and chooses the options to be shown as follows: a firm that cuts its price today is rewarded by being shown not only today but also in one or more future periods, even if rivals then offer lower prices. In equilibrium, for properly sized future revenues, all firms compete to be shown, and the effect is a breakdown in coordination.[198] Platforms may be incentivized to operate in this fashion by their increased attractiveness to consumers (and therefore increased profits).[199] Alternatively, platforms could also be legally obligated to promote competition in their marketplaces. This interesting suggestion is limited, however, to platforms. Also, its welfare effects (including the effects of limiting the variety of options available to consumers) must be analyzed.

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192. Francisco Beneke & Mark-Oliver Mackenrodt, *Remedies for Algorithmic Tacit Collusion*, 9 J. ANTITRUST ENFORCEMENT 123, 152 (2021).

193. Aleksandra Lamontanaro, *Bounty Hunters for Algorithmic Cartels: An Old Solution for a New Problem* 30 FORDHAM INTELL. PROP., MEDIA & ENT. L.J. 1259, 1302–07 (2020).

194. Gautier, Ittoo & Van Cleynenbreugel, *supra* note 115, at 430.

195. Barbora Jedlickova, *Digital Polyopoly*, 42 WORLD COMPETITION 309, 329–30 (2019); DONINI, *supra* note 3, at 93–94.

196. MARC WIGGERS, ROBIN A. STRUIJLAART & JOHANNES DIBBITS, DIGITAL COMPETITION LAW IN EUROPE: A CONCISE GUIDE, 105 (2019).

197. Justin Pappas Johnson, Andrew Rhodes & Matthijs Wildenbeest, *Platform Design when Sellers Use Pricing Algorithms* (Cornell Univ., Working Paper No. 1146, 2021).

198. *Id.* at 9 (for consumers to benefit from limited choice, it is crucial that such a policy causes firms to make procompetitive decisions that they otherwise would not).

199. *Id.* at 26–27.

Finally, Hulicki suggests employing government-operated algorithms to set market-clearing prices, to prevent inefficient pricing. [200] Beyond the immeasurable informational problems involved in setting such prices, this amounts to direct regulation.

Interestingly, some remedies that were suggested with regard to human oligopolistic coordination are no longer raised with regard to algorithmic coordination. Famously, a 1968 White House Task Force Report on Antitrust Policy suggested a de-concentration approach: breaking up the largest firms in highly concentrated markets, in order to artificially introduce more competition into oligopolistic markets. [201] While this remedy may be problematic on many grounds, algorithms strengthen its inefficiency, due to the fact that coordination can be sustained in less concentrated markets, a point we return to in the discussion regarding merger policy.

V. FOUR INNOVATIVE REMEDIES

These limitations of existing and proposed solutions highlight the need to envision remedial roads not taken. In the following Sections, I propose four innovative remedies. One is market-based, while the others require regulatory intervention. Three of the solutions employ algorithms to limit harms created by other algorithms.

All of these suggestions attempt to indirectly influence market conditions in order to introduce stronger competitive pressures on the supply side or by creating countervailing market power on the demand side, rather than placing direct limits on the ability of firms to engage in autonomous algorithmic coordination. The reason relates to the discussion above: we do not have a good theory of which degree of reliance on one's rivals' prices is optimal for creating efficient incentives for firms to invest in productive and dynamic efficiency.

A. INTRODUCING A COUNTER-FORCE: ALGORITHMIC CONSUMERS

Let us start with a partial solution that can be provided by the market. In his famous book *Exit, Voice, and Loyalty*, Albert Hirschman explored two ways in which consumers can respond to deteriorating quality in a market: withdraw from the relationship ("exit") or voice their discontent in an attempt to repair the relationship ("voice"). [202] Here we suggest a third way: creating a

200. Hulicki, *supra* note 134, at 252.

201. Reprinted in 2 ANTITRUST L. & ECON. REV. 11 (1968–1969). It was based on the work of CARL KAYSEN & DONALD F. TURNER, ANTITRUST POLICY-AN ECONOMIC AND LEGAL ANALYSIS 27 (1959); Turner, *The Scope*, *supra* note 168, at 1231.

202. *See generally* ALBERT O. HIRSCHMAN, EXIT, VOICE, AND LOYALTY: RESPONSES TO DECLINE IN FIRMS, ORGANIZATIONS, AND STATES (1970).

counterforce that would change market dynamics, in the form of algorithmic consumers. These are algorithms, operated by consumers, consumer groups, or third parties, that make purchase decisions on behalf of consumers and act as agents for buyers.[203] This solution involves the use of algorithms on the demand side to disrupt algorithmic coordination on the supply side. One of their main benefits is that they do not require direct regulatory intervention in the decisions of pricing algorithms or those of algorithmic consumers.[204] Gal and Elkin-Koren have developed this suggestion mainly with regard to dealing with unilateral market power, but it may also be useful to fight multilateral market power.[205]

Beyond the reductions they might offer in search and transaction costs, algorithmic consumers can help limit algorithmic coordination in several ways. All models of algorithmic coordination assume that transactions take place at prices exhibited online, which are transparent to all, and that most transactions are small and frequent, implying that consumers do not have buying power. Algorithmic consumers can challenge both assumptions. By aggregating consumers into buying groups, they can increase the size and reduce the frequency of transactions with each seller made through them. This can be done through the creation of a buying platform operated by one algorithm or by several algorithmic consumers joining forces. The available technology makes the formation of buying groups easier than ever.[206] Moreover, consumers need not all have similar preferences with regard to products they wish to buy for algorithmic consumers to have buyer power.[207] The business models of such automated buyer groups can be based, for example, on a small percentage of the costs saved.

Where algorithmic consumers have buying power, they can potentially break coordination between sellers by introducing another element into each supplier's decision-making: the ability to supply a large quantity at lower price. The resulting increase in the profits can potentially weaken the stability of the

203. Michal S. Gal & Niva Elkin-Koren, *Algorithmic Consumers*, 30 HARV. J.L. & TECH. 309, 310 (2017).

204. Some indirect regulation may nonetheless be required—for example, to ensure that consumers who use such algorithms can capitalize on their collective bargaining position without infringing antitrust laws. *See id.* at 340–52.

205. *Id.* at 341, 345.

206. *Id.* at 331–32.

207. Buyer power refers to the ability of buyers to influence the terms of trade with their suppliers. Joint buying algorithms may generate significant market power for consumers if a significant proportion of buyers choose to make their purchases through them. *See* OECD, DAF/COMP (2008) 38, MONOPSONY & BUYER POWER 9 (2009). Buyer groups are established to take advantage of economies of scale and scope. *See* Peter C. Carstensen, *Buyer Cartels Versus Buying Groups: Legal Distinctions, Competitive Realities, and Antitrust Policy*, 1 WM. & MARY BUS. L. REV. 1, 13–14 (2010).

coordinated conduct. Alternatively, should algorithmic consumers represent a sufficiently large number of consumers, they could negotiate a deal outside the digital sphere. Such external deals need not affect the price exhibited online, and thus may not be known to other suppliers. This implies that others will not retaliate, thereby increasing the incentives of the deviating supplier to agree to such a deal.[208] By reducing demand for other players, such external deals will also introduce "noise" into the ability of supplier algorithms to separate reductions of demand that result from deviations of rivals from the supra-competitive equilibrium, and those that result from external market conditions.

Given their analytical sophistication, algorithmic consumers can test, devise, and apply other strategies to motivate suppliers to reduce prices. Thus, they can take advantage of the benefits of AI to assist consumers, rather than suppliers. For example, while each consumer's demand may be inelastic, their cumulative demand could become elastic. Hence, algorithmic consumers could decide not to buy beyond a certain price. Algorithmic consumers could also delay demand signals, which could then lower prices.[209] In doing so, algorithmic consumers reduce consumers' collective action problem.[210]

Finally, and no less importantly, algorithmic consumers may reduce the extent of network effects, thereby potentially reducing the efficient size of market participants and creating more fragmented and contestable markets, which might be less prone to coordination. This claim is based on the nature of network effects, which arise when one's value from the use of a certain product increases with the number of other users of the same product. Take, for example, a platform that hosts numerous suppliers. The consumer can enjoy the one-stop-shop and the ability of the platform to compare among suppliers and provide him with the best results according to his preferences. Now compare this to multi-homing. Should the consumer need to compare offers of different products offered on several different platforms, it might take him a much longer time to explore all offers. More importantly, it might not be as easy for him to compare offers from different networks. But what if an algorithmic consumer were, instead, to engage in such tasks efficiently and cheaply? Then the size of the network would be less relevant.

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208. Note, however, that this solution might require human involvement.

209. Myklos-Thal & Tucker as well as O'Connor & Wilson find that more precise demand estimation generally impedes collusion. Miklós-Thal & Tucker, *supra* note 97; Jason O'Connor & Nathan E. Wilson, *Reduced Demand Uncertainty and the Sustainability of Collusion: How AI Could Affect Competition*, 54 INFO. ECON. POL'Y (2021). *But see* Harrington, *supra* note 51, at 3 (finding a different result when the pricing algorithm is not designed by the firm but by a third party).

210. This assumes, of course, that those using the algorithm have the flexibility to wait until the supplier changes its terms. Nonetheless, a supplier anticipating the market power of an algorithmic consumer might change its terms a priori.

Of course, such a solution has limitations.[211] For instance, algorithmic consumers risk creating a monopsony, either via unilateral market power or where several algorithmic consumers coordinate their conduct. The short-term consequences of the exercise of such market power are distributive, as the buyer captures more of the surplus from the trade. Total surplus and efficiency are unaffected because the quantity of inputs brought to market is the same as under competition. In the long run, however, the monopsonist's extraction of surplus may discourage entry by suppliers, which could impact consumers through reduced supplier competition.[212] To reduce such effects, such power is subject to antitrust limitations.[213] But more importantly, two points of control critically shape algorithmic consumers' ability to operate in markets: access to relevant data and access to potential users.[214] Let us first relate to the former. To use a common example, the requirement on many websites that users prove they are "not a robot," limits the ability of algorithmic consumers to operate. In fact, a middleware market for "bot mitigation" technology has emerged.[215] While such technology is generally used to hinder automated data scraping by sellers, it can equally be used to block activity by algorithmic consumers. Limitations on such technology might then need to be set by the regulator.[216] Furthermore, as Van Loo has suggested, mandatory disclosure of pricing and product data might even be requited in some settings.[217] Gal and

211. For elaboration, see Gal & Elkin-Koren, *supra* note 203, at 322–25 (analyzing efficiency-related shortcomings); Michal S. Gal, *Algorithmic Challenges to Autonomous Choice*, 25 MICH. TECH. L. REV. 59 (2018) (analyzing autonomy-related shortcomings).

212. Roger Noll, *Buyer Power and Economic Policy*, 72 ANTITRUST L.J. 589, 606 (2005).

213. Gal & Elkin-Koren, *supra* note 203, at 331–34.

214. *Id.* at 334.

215. Klint Finley, *'Scraper' Bots and the Secret Internet Arms Race*, WIRED (July 23, 2018, 7:00 AM), https://www.wired.com/story/scraper-bots-and-the-secret-internet-arms-race/.

216. The Supreme Court has recently dealt with the issue of content scraping in *LinkedIn Corp. v. hiQ Labs, Inc.*, 141 S. Ct. 2752 (2021). LinkedIn informed HiQ that it was not permitted to scrape data from public profiles of its users available on its website. HiQ argued that it required access to the data to compete. The Court vacated the Ninth Circuit's decision to enable such access and remanded for reconsideration in light of its recent decision in *Van Buren v. United States*, 593 U.S. (2021), which focused on the Consumer Fraud and Abuse Act. On remand, the Ninth Circuit found such scraping to be legal, as there was no unauthorized use of a computer. *HiQ Labs, Inc. v. LinkedIn Corp.*, 31 F.4th 1180 (9th Cir. 2022).

217. Rory Van Loo, *Helping Buyers Beware: The Need for Supervision of Big Retail,* 163 U. PA. L. REV. 1311, 1330 (2015) (proposing legal reforms that would enable third-party pricing tools that would counter sellers' pricing sophistication by enabling the pricing tool to "aggregate prices from all relevant brick-and-mortar and online retailers and run sophisticated algorithms to create optimized shopping itineraries from which the consumer could choose").

Rubinfeld have suggested that some form of data standardization might also be required in some settings.[218]

Let us now relate to access to potential users. In today's digital world, access to intermediary platforms is generally essential to reach users (for example, through an app store). As a result, digital intermediaries can affect which algorithmic consumers reach potential users and on what terms. Furthermore, given that algorithmic consumers may become users' gateway into the digitized marketplace, platforms may attempt to provide and control such algorithms.[219] Indeed, the major digital platforms are already racing to develop digital shopping assistants.[220] Their motivation to do so is strengthened by the fact that in aggregating consumers' data, algorithmic consumers obscure the preferences of individual consumers, thereby harming the business models of platforms whose value depends on such data. The more important the access to the unique data held by the intermediary, the more likely that platforms will attempt to control or regulate such access.[221] This, in turn, strengthens the importance of regulation designed to limit the creation of artificial barriers blocking access to both data and consumers, and to ensure that consumers are getting the bulk of the benefits, rather than intermediaries.[222]

Algorithmic consumers could also generate new harms and risks, such as limiting consumer choice and autonomy, increasing consumers' vulnerability to inefficient decisions made on their behalf, and raising the risk of cyber-security harms. Their use may also have psychological and social implications. All of these are beyond the scope of this paper, and have been partly addressed elsewhere.[223]

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218. Michal Gal & Daniel L. Rubinfeld, *Data Standardization*, 94 NYU L. REV. 737, 749–51 (2019).

219. Ariel Ezrachi & Maurice E. Stucke, *Is Your Digital Assistant Devious? In* RECONCILING EFFICIENCY AND EQUITY: A GLOBAL CHALLENGE FOR COMPETITION POLICY 220 (Damien Gerard & Ioannis Lianos eds., 2019).

220. *See* Mark Prigg, *Apple Unleashes Its AI: 'Super Siri' Will Battle Amazon, Facebook and Google in Smart Assistant Wars*, DAILY MAIL (June 13, 2016), http://www.dailymail.co.uk/sciencetech/article-3639325/Apple-unveil-SuperSiri-Amazon-Google-smart-assistant-wars.html.

221. EZRACHI & STUCKE, *supra* note 14, at 191–92.

222. For a suggestion to apply agency law to voice shoppers, see, e.g., Noga Blickstein-Shchory & Michal Gal, *Voice Shoppers: From Information Gaps to Choice Gaps in Consumer Markets*, 88 BROOKLYN L. REV. 111, 143–61 (2022); *see also* Rory Van Loo, *Rise of the Digital Regulator*, 66 DUKE L.J. 1267 (2017) (suggesting the application of oversight mechanism to algorithmic regulators).

223. *See, e.g.,* Gal, *supra* note 211, at 80–90 (focusing on harms from loss of autonomous choice).

B. MERGER REVIEW: WHEN THE EXCEPTION BECOMES THE RULE

The Article now turns to exploring remedies that require direct governmental intervention. We start with the one that strays the least from conventional regulation: merger review. Merger regulation was traditionally seen as the main tool in our arsenal to limit oligopolistic coordination, the same type of conduct which underlies algorithmic coordination.[224] As elaborated below, merger regulation can still be used to limit some instances of the latter, but to do so some of its presumptions need to change in a subset of cases where market conditions seem conducive to algorithmic coordination.[225] Many of the suggestions made here also pertain to the regulation of joint ventures.

On its face, algorithmic coordination makes merger review less relevant. This is because algorithmic coordination may reduce firms' incentives to merge. That is, if coordination can be facilitated by algorithms under a wider range of market conditions, with the resulting equilibriums even more stable than before, then firms have weaker incentives to merge to increase their profits via coordination.[226]

Algorithmic coordination also makes some merger tools less effective. One of the main tools in the merger review arsenal involves preserving asymmetries and heterogeneities between market participants.[227] Doing so, it is believed, protects competition by making it harder for firms to coordinate. Yet if algorithms can at least partially overcome some of these traditional obstacles to coordination, then preserving such market conditions would not have a significant effect on competition.[228]

Still, merger review has an important role to play. Its wide scope for inquiry, the fact that it is outcome-based rather than process-based, and the

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224. *See, e.g.*, Nicolas Petit, *The Oligopoly Problem in EU Competition Law*, *in* HANDBOOK IN EUROPEAN COMPETITION LAW (Ioannis Liannos & Damien Geradin eds., 2013).

225. For an outstanding analysis of some of the effects of algorithmic coordination on merger policy, see Coutts, *supra* note 26.

226. Ariel Ezrachi & Maurice E. Stucke, *Two Artificial Neural Networks Meet in an Online Hub and Change the Future (Of Competition, Market Dynamics and Society)* (Univ. Tenn. Coll. L., Legal Stud. Rsch. Paper Ser. No. 323, 2017).

227. *See, e.g.*, DEP'T JUST. & FED. TRADE COMM'N, HORIZONTAL MERGER GUIDELINES ¶ 7 (1997) *see also* U.K. COMPETITION & MKTS. AUTH, MERGER ASSESSMENT GUIDELINES ¶ 5.5.11 (2010).

228. *See* Coutts, *supra* note 26, at 15–22 (arguing, for example, that algorithms can mitigate market complexity by determining focal points or understanding "invitations to collude" that a human could not; by reacting in a speedier way; and steering firms towards pricing strategies that take a long-term view of profitability when balancing the prospects of short term and long-term gains). Algorithms may assist in overcoming asymmetry among would-be colluders through better estimation of competitors' otherwise private information, by reconciling competing incentives and preferred equilibria, and by easing the implementation of an effective reward/punishment scheme amongst asymmetric firms. *Id.*

flexibility of its potential remedies all increase its potential effectiveness.[229] Its importance is further strengthened by the fact that algorithmic coordination is not captured by any other existing regulatory tool, and by the fact that it does not involve prohibiting or declaring the use of the algorithm (or part thereof) as illegal. I suggest that merger review can play a double, interconnected role. First, merger review should be used to prohibit mergers that increase algorithmic coordination without offsetting benefits. Second, remedies should be designed to give more weight to the possibility of algorithmic coordination. Incorporating these considerations might increase uncertainty and require authorities to expend more resources determining the actual potential for and effects of algorithmic coordination on welfare. But disregarding them might be a far worse option.

Some parts of the existing merger guidelines, or the way they are applied in practice, fit well with the need to consider the possibility of algorithmic regulation, such as the requirement to analyze whether the post-market conditions would be more conducive to coordination. Nonetheless, algorithmic coordination may need to be further reflected in two main ways: (1) in the change of relevant presumptions (such as with regard to the importance of asymmetry in the market to reduce coordination); (2) in the active analysis of the potential for algorithmic coordination, where algorithmic coordination is already prevalent or is potentially profitable.

Let us elaborate. We start with suggestions that pre-merger notification thresholds should be rethought and attuned to coordination in the age of algorithmic pricing.[230] Currently, mergers need to be reported to the antitrust authorities only if they meet a preset *financial turnover*.[231] In the presence of algorithmic coordination this might be insufficient, allowing some mergers that increase algorithmic coordination to fall under the radar. Consider two examples. In the first, the acquired firm has limited financial turnover but its algorithm acts as a maverick, disrupting the coordinated equilibrium. In the second, the acquired firm's algorithm or dataset constitutes its main competitive asset. As elaborated below, a better algorithm, or a better dataset to train the algorithm on, could better facilitate algorithmic coordination. Yet the owner might have limited financial turnover, inter alia because the algorithm or dataset has not yet been used commercially—whether as a strategic decision, to ensure that the merger is not captured under current merger review thresholds,[232] or because the owner does not have the ability to

229. *See id.*

230. Ezrachi & Stucke, *supra* note 226, at 46; Coutts, *supra* note 26.

231. 15 U.S.C. § 18a (2021) (the current version of Clayton Act 7A).

232. Merger control enables the antitrust authorities to review mergers which did not meet the benchmark for reporting. Yet the authorities might not be aware of such mergers.

enjoy their potential. In such cases, the German solution for detecting "killer acquisitions" is valid here as well: adding a category to merger review thresholds based on the absolute value of the transaction.[233]

Turning to structural presumptions used to screen mergers, so far, prohibiting a merger based on coordinated effects has been the exception. There are two main reasons: (1) there are no definite models on which market conditions facilitate coordination, and (2) it is generally assumed that oligopolistic coordination can take place only in extreme cases, where the market is highly concentrated, and firms are relatively homogenous in size. Accordingly, concentration parameters are given substantial weight in determining intervention thresholds.[234] The level at which these parameters are set is based on the assumption that mergers in markets with more than three players will not be prone to coordination.[235] Algorithmic coordination challenges these assumptions, given the algorithms can potentially increase the number of firms that can potentially coordinate effectively. Thus, we should explore the possibility that high levels of concentration—and their indicators—should be given less weight in markets prone to algorithmic coordination.

Relatedly, levels of concentration which serve as thresholds for intervention might need to be lowered. How low such thresholds should be set, and under what market conditions, should be based on careful economic analysis. The OECD recommended that the threshold be lowered to capture even five-to-four transactions.[236] Ezrachi and Stucke suggested to lower it to five-to-six significant players.[237] Under some market conditions algorithms may enable coordination even beyond such thresholds. Take, for example, follow-the-leader pricing algorithms in markets where price matching is instantaneous, so that the immediate benefits to one rival of lowering prices are miniscule.[238] Furthermore, Coutts suggests that determining such levels should also relate to other market conditions, such as transparency and frequency of interaction, which affect coordination.[239] This implies that intervention thresholds might have to be more sensitive to industry-specific

233. FEDERAL CARTEL OFFICE (BKARTA) & FEDERAL COMPETITION AUTHORITY (BWB), GUIDANCE ON TRANSACTION VALUE THRESHOLDS FOR MANDATORY PRE-MERGER NOTIFICATION (SECTION 35 (1A) GWB AND SECTION 9 (4) KARTG) (July 2018); Claire Turgot, *Killer Acquisitions in Digital Markets: Evaluating the Effectiveness of the EU Merger Control Regime*, 5 EUR. COMPETITION & REG. L. REV. 112, 118 (2021).

234. U.K. COMPETITION & MKTS. AUTH, *supra* note 227, ¶ 1.5.

235. *Id.*

236. OECD, *supra* note 10, at 41.

237. Ezrachi & Stucke, supra note 226, at 31.

238. Gal, *supra* note 38, at 85–86.

239. Coutts, *supra* note 26.

conditions, and may even be dynamic. This implies, of course, that more regulatory and private resources should be spent on merger control. Accordingly, it should only be applied in those markets in which conditions are rife for algorithmic coordination and there is wide(ning) use of such algorithms.

Let us now turn to the factors that play a role in a more in-depth analysis of the potential harms of the merger. The antitrust agencies' Horizontal Merger Guidelines clearly state that they "will examine the extent to which post-merger market conditions are conducive to reaching terms of coordination, detecting deviations from those terms, and punishing such deviations."[240] They are thus sufficiently wide to take into account the possibility and potential effects of algorithmic coordination. Yet they would need to be attuned to this possibility. As noted above, as a result, some mergers might be allowed to go through. Yet, in other cases, the increased potential for algorithmic coordination might require prohibiting mergers that would have otherwise been allowed. Let us explore five relevant scenarios.

In the first scenario, the merger will shorten the time needed to reach coordination. To illustrate, assume a market with five market players. Three adopt a follow-the-leader pricing algorithm, while two adopt learning algorithms which are given the task of price maximization. As Calvano et al. found, even in a lab setting, it took learning algorithms a long time to coordinate.[241] But if the merger takes one learning algorithm out of the game, coordination may be more easily achieved. One question to ask is why one of the firms did not simply also switch to a follow-the-leader algorithm in the pre-merger situation. The answer might be based on trust issues, on ensuring that the leader actually sets the best prices, or even on the assumption that a learning algorithm is less prone to regulatory scrutiny.

In the second scenario, market dynamics are changed by the acquisition of a firm for its dataset, on which the algorithm is run or trained.[242] In such cases data can be likened to the input for the production facility (the algorithm). One of the main obstacles to coordination recognized in the economic literature is that market players cannot easily distinguish between changes in market conditions that result from external factors, and those that result from an

240. U.K. COMPETITION & MKTS. AUTH, *supra* note 227, ¶ 2.1 (emphasis added).

241. Calvano et al., *Artificial Intelligence, supra* note 17.

242. The importance of algorithms and data as important parameters in merger review have already been recognized. *See, e.g.*, Anca Chirita, *Data-Driven Mergers Under EU Competition Law*, *in* THE FUTURE OF COMMERCIAL LAW: WAYS FORWARD FOR HARMONISATION 147 (John Linarelli & Orkun Akseli eds., 2019); MARIA WASASTJERNA, BIG DATA AND PRIVACY IN MERGER REVIEW - COMPETITION POLICY FOR THE 21ST CENTURY DIGITAL ECONOMY (2020).

attempt to deviate from the coordinated equilibrium.[243] Where a dataset creates better knowledge that makes it easier to differentiate between these factors, coordination may be more efficient. Finally, a merger leading to more homogenized and accurate input data might strengthen the incentive of other firms in the market to use follower-leader pricing algorithm.[244]

The third scenario involves the acquisition of a firm for its algorithm. Should the algorithm not otherwise be easily transparent in the pre-merger scenario, such a merger can reduce uncertainty concerning how a rival sets his prices. Alternatively, acquiring an efficient algorithm can shorten the time needed to reach coordination. Finally, an efficient algorithm, which reduces the need for data, may increase firms' ability to coordinate in complex situations. Interestingly, the British Competition and Markets Authority already recognized such effects when weighing whether to approve Amazon's acquisition of a minority shareholding in Deliveroo.[245] As part of their submissions, the merging parties had to show that their algorithms were differently structured and optimized.

The fourth scenario relates to conglomerate mergers, which are generally assumed to be benign, and thus are rarely prohibited. The sophistication of algorithms can change this. As Donini suggests, since pricing algorithms can respond to punishment mechanisms even in distinct product industries through multi-market contacts,[246] antitrust authorities should more carefully scrutinize conglomerate mergers, particularly those between firms offering the same type of product in different geographic markets.[247]

Finally, the use of sophisticated algorithms in the industry can affect the merger counterfactual. That is, the hypothetical scenario which is assumed to exist should the merger not be allowed to take place. Take, for example, asymmetry. Under some circumstances, pricing algorithms can increase the incentives and ability of asymmetric firms to coordinate. This is because algorithmic modeling can help firms understand their asymmetric competitors as well as the prevailing demand conditions, which simplify the process of establishing a supra-competitive equilibrium.[248]

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243. Beneke & Mackenrodt, *supra* note 192, at 126–27.

244. Ai Deng & Christian Hernandez, A*lgorithmic Pricing in Horizontal Mergers: An Initial Assessment*, 32 ANTITRUST (2022).

245. UK COMPETITION & MKTS. AUTH., ANTICIPATED ACQUISITION BY AMAZON OF A MINORITY SHAREHOLDING AND CERTAIN RIGHTS IN DELIVEROO: FINAL REPORT ¶ 46 (2020).

246. Federico Ciliberto & Jonathan W. William, *Does Multimarket Contact Facilitate Tacit Collusion? Inference on Conduct Parameters in the Airline Industry* 45 RAND J. ECON. 765 (2014).

247. DONINI, *supra* note 3, at 105.

248. Coutts, *supra* note 26, at 28.

Algorithmic coordination also affects presumptions relating to potential efficiencies. If firms can achieve high profits through algorithmic coordination, under some conditions they might prefer this over a merger (e.g., because it is legal and thus not subject to regulatory scrutiny). In that case, ceteris paribus, firms that merge are more likely to do so for other reasons, such as to realize efficiencies. This is because if both a merger and a coordinated scheme can raise prices, the difference in control rights of the owners in both cases leads to a stronger probability that the merger route was chosen because it will better enable the realization of scale and scope economies, where they exist.[249] Imagine an industry where the minimum efficient scale supports three players, but algorithmic coordination can sustain six players. From a welfare perspective, it might be better to have three players, operating at efficient levels, to reduce productive inefficiency. This should not lead, however, to a "hands off" merger approach, but only to recognition of the possibility that the merger is not designed only to increase prices.

The above analysis implies that there is a need to develop more nuanced evaluations of mergers that might lead to algorithmic coordination, while also ensuring a sufficient level of certainty. The task is not an easy one. One of the reasons mergers are rarely prohibited due to their potential effects on coordination is that there are no bright lines that determine when a market will be prone to coordination. Instead, economic analysis recognizes factors that might lead to coordination and general tendencies.[250] Algorithmic coordination further complicates the analysis. One suggestion, made recently by the UK's Digital Competition Expert Panel, is for a balance of harms approach, which would consider both the likelihood and the magnitude of the merger's impact. This would involve an overall assessment based on potential risks under all factual and counterfactual scenarios.[251] Of course, this suggestion does not fully resolve the problem, as counterfactuals may be difficult to evaluate. Yet once data scientists and computer scientists are added to investigatory teams and competition authorities create more rigorous tools to evaluate the effects of mergers in markets where pricing algorithms are common, and even to monitor behavioral remedies in the post-merger world, these tasks might seem a bit less formidable.

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249. *See* George Baker, Robert Gibbons & Kevin J. Murphy, *Strategic Alliances: Bridges Between "Islands of Conscious Power*,*"* 22 J. JAPANESE & INT'L ECON. 146 (2008) (classifying organizational forms that differentiate between a merger, a strategic alliance, and a joint venture).

250. U.K. COMPETITION & MKTS. AUTH, *supra* note 227, ¶ 2.12.

251. DIGIT. COMPETITION EXPERT PANEL, UNLOCKING DIGITAL COMPETITION (2019), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/785547/unlocking_digital_competition_furman_review_web.pdf.

As Coutts convincingly argues, the potential for algorithmic coordination should also affect the *pre-merger procedure*: care should be taken to limit abuses of this procedure.[252] Under certain circumstances, disclosure of a pricing algorithm may contravene antitrust prohibitions on the sharing of competitively sensitive information.[253] While such disclosure might be required to expose the assets that may create value, it could also increase algorithmic coordination through signaling, or by reducing the need for experimentation and uncertainty where the algorithm is not otherwise directly transparent.[254] Such exposure might have long-term effects even if the merger is abandoned. In fact, in such a case, antitrust authorities would generally not even know that a merger was contemplated, because there is no reporting requirement. Firms could abuse this fact, exposing their algorithms and datasets under the guise of a potential merger, without seriously contemplating one.[255]

To address such issues, Coutts suggests that due diligence be structured to increase the sensitivity of certain types of information that would ordinarily be permissible to disclose.[256] For example, ordinarily, information becomes less competitively sensitive as it becomes less current. Yet a dataset on past market conditions could reduce welfare if it facilitates algorithmic coordination. This might imply that absent strong pro-competitive justifications, firms should be permitted only to expose the level of revenue their algorithm generates above costs, but not the actual content of the algorithm. Or they may be allowed to expose the algorithm or the dataset only to a third party. While theoretically such conduct might be captured as facilitating practices, the fact that it might be justified as part of a due diligence process could limit this possibility.

Finally, as Coutts suggests, algorithmic coordination makes structural remedies less effective. As he contends, increasing asymmetries reduces the likelihood of coordinated effects but raises the likelihood of unilateral effects, and vice versa.[257] Accordingly, where pricing algorithms are ubiquitous, the propensity for symmetric remedies backfiring increases significantly. This is because increasing the symmetry of market participants in order to address concerns of unilateral effects (or coordinated effects vis-à-vis asymmetric price

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252. Coutts, *supra* note 26.

253. *Id.*

254. *Id.*

255. *Id.*

256. *Id.*

257. Luke Garrod & Matthew Olczak, *Collusion under Imperfect Monitoring with Asymmetric Firms*, 65 J. INDUS. ECON. 654, 656 (2017).

leadership) might reduce consumer welfare than simply allowing the merger to proceed unmodified.[258]

As the above analysis shows, merger review tools can no longer disregard the potential for algorithmic coordination. On the one hand, this potential may weaken the justification for prohibiting mergers on the grounds that they increase concentration. On the other hand, merger review has an important role to play in limiting some situations where mergers increase the possibility of algorithmic coordination. As the antitrust authorities have recently announced that they are considering a revision of their merger guidelines,[259] there is no better time to consider incorporating in them the effects of algorithmic coordination. This is also the time to consider adding computer and data scientist to the antitrust authorities, and increase the financial resources in order to employ them.

Interestingly, it is not clear whether, in the long run, making merger analysis tools more sensitive to algorithmic coordination will increase or decrease merger review costs. This depends, inter alia, on whether the potential for algorithmic coordination under different market conditions will be found to imply that such coordination requires a more complicated and resource-intensive case-by-case analysis, or that preventing mergers is not effective in many markets, and so in-depth investigations should be limited to a sub-set of mergers in which it can be assumed that the merger will harm competition, like the cases explored above.

C. DISRUPTIVE ALGORITHMS: TURNING AUTOMATION INTO AUTONOMY

The Article now turns to two remedies that require active governmental intervention in market conditions. The first is the introduction of a disruptive algorithm. The idea behind this remedy is to use algorithms on the supply side to change market conditions in a way which makes it more difficult for algorithmic coordination to emerge. A basic insight from the economic theory of coordination is that "noise"—(perceived) changes in market conditions which may change the optimal equilibrium—makes coordination more difficult.[260] Deployment of a disruptive algorithm, which is given the task of

258. *Id.*

259. The British Competition and Markets Authority, for example, recognized the effects of algorithms on swiftness of response, as well as their being sensitive information about rivals that could be exposed during a merger. This is a first step in the right direction, but more careful analysis is still needed. U.K. COMPETITION & MKTS. AUTH, MERGER ASSESSMENT GUIDELINES 50, 53 (2021), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1051823/MAGs_for_publication_2021_—_.pdf.

260. Edward J. Green & Robert H. Porter, *Noncooperative Collusion under Imperfect Price Information*, 52 ECONOMETRICA 87, 94–95 (1984).

introducing noise, can potentially limit the ability of other algorithms to engage in coordinated conduct.[261] The interference is external and mimics the entry into the market of a maverick supplier that does not adhere to the coordinated equilibrium.[262]

The scheme is quite simple: as elaborated below, one supplier, who operates the disruptive algorithm, will be incentivized by consumers or by a regulator to charge lower, potentially competitive prices, for a period of time. The algorithms of other firms may then find it optimal to lower their prices as well, to the benefit of consumers. Otherwise, under the market conditions elaborated below, they will lose too many consumers for their higher prices to remain profitable. Indeed, as Assad et al. show in their empirical study of German gas retailers, for supra-competitive prices to arise under the conditions they studied, all firms must adopt pricing algorithms that seek to maximize profits.[263] This serves as an indication that a disruptive algorithm may limit supra-competitive coordination under some market conditions. It also leads to the observation that different markets might need different types of disruptions. Observe that price need not be the only parameter that can cause disruption. Other parameters might include, inter alia, better service conditions and lower prices of related products.

Disruptive algorithms can be operated by the regulator, but this is a tall order, given that the regulator has no capacity of supply and no expertise in the production and marketing of such products. A preferred solution is to subsidize one of the suppliers in the market. Why would a firm agree to cooperate?[264] A firm might expect to realize scale economies in the post-intervention period. But more importantly, each supplier faces a prisoner's dilemma. Firms must respond to the regulator's offer without knowing the intentions of competing suppliers. If all suppliers decline to cooperate, they can all maintain their supra-competitive prices. But if one supplier agrees to cooperate, his profits will be increased by the financial incentives offered by the regulator, while his rivals will incur losses. Each supplier is thus motivated to cooperate by the threat that another supplier would agree.

Disruptive algorithms can also be potentially operated by large consumers, consumer associations, or government-supported private firms. Yet

261. DONINI, *supra* note 3, at 115–16.

262. A version of this potential remedy was first suggested by Gal in the context of human oligopolistic coordination, but it may apply here as well, subject to necessary changes. Michal S. Gal, *Reducing Rivals' Prices: Government-Supported Mavericks as New Solutions for Oligopoly Pricing*, 7 STAN. J.L., BUS. & FIN. 73 (2001). Other scholars reiterated this potential remedy. *See, e.g.*, DONINI, *supra* note 3, at 61, 115–116; Michal Gal & Nicolas Petit, *Radical Restorative Remedies for Digital Markets*, 36 BERKELEY TECH. L.J. 617, 653–62 (2021).

263. Assad et al., *supra*, note 9, at 29.

264. Gal, *supra* note 262.

government funding might still be required, given the direct costs of operating such a disruptor and the fact that the positive externalities it creates will benefit all consumers, with no special advantages for the private entity operating the disruptor. Deployment of a disruptive algorithm has clear upsides. If successful, it introduces direct competition into the market. Furthermore, the threat of governmental intervention might, in itself, create incentives for firms to reduce price levels in their markets. In addition, it avoids determining which elements the firm can take into account when making its trade terms decisions, no firm is forced to act in a manner that contravenes its incentives, and there is no ongoing intervention except to check the price or trade terms set by the disruptive algorithm.

The success of such a remedy depends, inter alia, on how sensitive the pricing algorithms are to noise on the supply side. In particular, the disruptive algorithm must be able to challenge the market equilibrium. For other suppliers to find it in their interest to follow the disruptor's pricing strategy, three conditions must exist.[265] First, there must be a credible threat that the disruptor will attract consumers who were previously served by his rivals, should the latter not follow suit in reducing prices. If the disruptor has limited capacity for supply, and if this can be easily detected by other algorithms, it might still be profit-maximizing for the others to engage in algorithmic coordination at supra-competitive prices. For the scheme to work, either the disruptor's capacity must be quite large (or relatively easily enlarged), or its limited capacity must not be easily detected by competing suppliers. Note, however, that once the disruptor expands its capacity, the market will have to accommodate a larger-scale rival. If the expansion allows the disruptor to realize scale and learning economies not realizable by incumbents, the threat of increased capacity alone may stimulate firms to reduce prices.[266]

The second condition is relative product homogeneity.[267] If each supplier enjoys niche demand for a branded or highly differentiated product, the price of the disruptor's product may have to be reduced considerably in order to significantly affect the demand for competing products. The third condition dictates that the duration of the product's life-cycle should be longer than the time it will take the disruptor to expand its capacity.[268]

How long should the government subsidize the disruptor?[269] The optimal length of time will vary from one industry to another, depending on market conditions. In general, it should be the minimal period that is sufficient to

265. *Id.*
266. *Id.*
267. *Id.*
268. *Id.*
269. *Id.* at 21.

incentivize market participants to assume the role of the disruptor, and to produce significant losses for rivals that fail to reduce their prices. In particular, time frame considerations must include how long it will take the disruptor to expand its output and significantly erode the market shares of its rivals. However, the government need not convey to all market participants the length of time that it will subsidize the disruptor.

Another question is how large the compensation offered should be. The answer depends on market conditions and the position of the disruptive firm in the subsidy and post-subsidy periods. The higher the barriers to competition, the higher the necessary subsidy. Compensation need not equal the full costs of expansion, since the added capacity may allow the disruptor to enjoy scale economies both during the subsidization period and afterwards. It also depends on the price charged by the disruptive firm. It should also cover any costs foreseen by the disruptor of retaliation of its rivals in subsequent periods, once the regulatory intervention period is over. In addition, the choice of which firm to subsidize could be auctioned, thereby reducing the need to determine a priori the size of the compensation offered.[270]

Finally, incumbent suppliers should be given an opportunity to take voluntary steps to restore competition and limit intervention before the introduction of a disruptive algorithm. The mere threat that a disruptive algorithm—subsidized by consumers or the government—will be employed may by itself stimulate market participants to reduce their prices.[271]

This remedy is not without problems. It demands high technological skills, which might be in short supply. Furthermore, it raises concerns regarding its effects on market dynamics.[272] Specifically, it could interfere with firms' incentives to enter oligopolistic markets and make investments that may lead to productive and dynamic efficiency. By reducing firms' ex post ability to enjoy supra-competitive profits, the remedy might undermine ex ante investment incentives. Recall, however, that we are discussing a case where high prices result from coordination, not from better products. Firms in oligopolistic markets have no inherent right that market conditions that sustain their ability to charge high prices will exist forever. In this sense, the introduction of the disruptive algorithm can be likened to a reduction in import barriers into the market. Yet the concern remains that the remedy could overreach, going beyond restoring the market to a competitive state, and

270. *Id.* at 96–100.

271. *Id.*

272. Bernhardt & Dewenter, *supra* note 30, at 337.

producing distortions of its own to the market's pricing system.[273] Accordingly, before applying this remedy, the effect of the disruptor on the market should be analyzed and simulated. Here we may take advantage of the nature of algorithms, and the fact that their strategies can often be tested and therefore anticipated. Such tests may be performed on the actual algorithms used by firms, or simulated based on uncovering the rules that lead to coordination in that market and analyzing their potential interactions. Note that the experimental and empirical studies performed so far have all assumed that all algorithms are programmed to maximize the profits of their operator, and that noise in the system comes mostly from changes in market conditions, which are external to all market players. Such experiments can be potentially extended to test the effects of introducing a disruptor algorithm into the market, whose goal is to break the coordination and lead to a lower-price equilibrium.

A final problem is that deploying a disruptive algorithm requires the regulator to take an active role in changing market conditions.[274] By limiting the disruptive algorithm to one firm while leaving the pricing, output, and quality decisions of all other firms in their own hands, intervention is significantly limited. Nonetheless, this remedy should only be used where welfare effects are significant and no less-interventionist remedy can achieve equivalent results.

D. COMPETITION-BY-DESIGN: MANDATORY TIME LAGS

As observed above, prohibiting the use of all pricing algorithms, or those that facilitate price coordination, is highly problematic. At the same time, small changes in the environment in which the algorithms operate might go a long way toward securing competition, while not directly interfering in the algorithms' design. Accordingly, the idea behind the fourth remedy is to create an artificial time lag in a pricing algorithm's ability to respond to changes in market conditions. This idea should be treated as a thought exercise, rather than a call for action, given its institutional limitations noted below.

This solution builds on an idea that was introduced several decades ago by Edlin in another context—combating the negative effects on competition dynamics of predatory pricing by a monopolist, where prices are lowered in the short run in order to drive out a competitor and increase prices in the long run.[275] Edlin suggested that price reductions should trigger a freeze of the

273. For the importance of legally gained profits as a stimulant for competition and innovation, see Verizon Commc'ns, Inc. v Law Offs. of Curtis V. Trinko, LLP, 540 U.S. 398 (2004).

274. Gal & Petit, *supra* note 262, at 662.

275. Edlin, *supra* note 35, at 945–46.

monopolist's price, thereby making it costlier for him to reduce prices in the short run and so making a predatory pricing strategy less profitable.[276] Interestingly, Austria adopted a version of this solution in practice. As of 2009, petrol stations have been allowed to reduce prices immediately, but any price rise, as a reaction to a price change by a rival, is allowed only after twenty four hours.[277] The idea behind this law is that firms will be more reluctant to raise prices, if they know that for twenty four hours their price will be higher than their rivals thereby losing sales during that period. I build on this idea, flip it, and adapt it for algorithmic coordination. Here, the purpose of the price freeze is the opposite: to prevent the setting of high prices in the first period, which others might follow in subsequent periods. The scheme works like this: once a supra-competitive equilibrium which is most likely derived from coordination is detected, the regulator can mandate one of the suppliers involved to freeze its price at the supra-competitive level. While the supplier is not limited to the quantity he may sell, the price, quality, level of service, and terms of sale, cannot be changed. The other suppliers will be free to price as they deem fit. Assuming the frozen price is above their costs, their algorithms may quickly learn that they can boost their profits by reducing their price to capture the capacity of the price-frozen firm, especially if the pricing algorithm they use is based on trial and error. The remedy can be repeated as needed, freezing the price of one supplier in each period. This, in turn, incentivizes any firm which might be subject to a price freeze to set its price at a lower level, either to ensure it retains its customers during the price freeze, or to avoid the freeze altogether ("anticipation effect"). To illustrate, assume an industry with five firms that coordinate prices on a supra-competitive level. Each has a 20% change that its price will be frozen. A firm's expected loss from price freeze, if it were to be chosen, amounts to $1,000,000 (due to lost sales). Thus, if it were risk-neutral, it would have an incentive to lower the price up to a level that would reduce its profits up to $200,000, in order to avoid a loss which is larger than its gain. This price incentive is further strengthened by a reputational effect that may result from such "naming and shaming." As a result, coordination could be broken, or at least should be achieved at lower pricing levels, with consumers benefiting in either case. Indeed, for price levels to be reduced, it might be sufficient that the anticipation effect lead only one firm to lower its price. In addition, should the price-frozen supplier engage in price discrimination (setting different prices for different consumers), the price freeze should relate to the highest price set. This, by itself, might limit

276. *Id.*

277. One limitation of this suggestion is that algorithms will quickly learn to take into account that once a price is reduced, it cannot quickly be raised. This might reduce their incentive to lower the price in the first place. DONINI, *supra* note 3, at 115.

incentives to engage in price discrimination. Observe that this solution can be applied to any part of the supply chain, from manufacturers to retailers.

The suggested remedy builds upon the fact that price-setting is by nature dynamic, with rivals' pricing decisions affected by one's own prices. It also takes advantage of the fact that coordination is inherently unstable, as each supplier has incentives to deviate from the coordinated price in order to increase his own profits at the expense of others. Indeed, it exploits, and flips on its head, the fact that the speed at which algorithms can detect price changes stabilizes oligopolistic coordination.[278] By doing so, it overcomes one of the main obstacles to such deviation in digital markets characterized by immediate detection of price deviations.

In temporal terms, the freeze should be sufficiently long to create incentives for firms to lower their price in order to avoid a price freeze. Relevant parameters include the volume and speed of transactions in the market, as well as the relative costs of other suppliers. However, the price freeze should not last so long as to make the price-frozen firm so unprofitable that it would have to exit the market. This is because in the long run, greater market concentration can harm consumer welfare.

To increase uncertainty, and therefore noise, the identity of the supplier who is mandated to freeze prices in each period, as well as the timing and the duration of the price freeze, should not be known ahead of time. Rather, the relevant supplier should be notified of its selection, and of the freeze's start and end dates, only close to such dates. To increase fairness, these parameters can be determined randomly by an algorithm which applies to all suppliers that meet certain criteria (such as having supply capacity beyond a minimal threshold). However, the algorithm may give weight to considerations that would increase the probability of success of the price freeze, such as the applying it to the firm which often raises prices before others or to a firm which most others tend to follow (both indicating a leader-follower pattern).

Of course, the price freeze solution is not bullet-proof. For it to work—i.e., for a price freeze on one to have significant effects on the pricing incentives of others—products must not be highly differentiated, and other suppliers must be able to supply the capacity of the price-frozen firm at lower prices. In addition, transactions must be relatively frequent and small, or the price freeze would need to be very long. Also, high barriers must exist for the price-frozen firm to switch to another market (wadgets rather than widgets). Furthermore, it requires other prices in the market to be relatively easily updated at the point of sale. Beyond these pragmatic considerations, since this remedy prohibits some firms from lowering their prices, it may (mistakenly)

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278. Ezrachi & Stucke, *supra* note 226, at 3–4, 26; Gal, *supra* note 38, at 78–79; UK COMPETITION & MKTS. AUTH., *supra* note 20, ¶¶ 2.21, 5.

raise doubts as to its regulatory legitimacy. Public relations efforts, potentially drawing on the outcomes of previous price freezes, may be needed to deal with this concern. Another concern is that if pricing algorithms play a multi-period game, under some market circumstances they may find it profitable not to deviate. Finally, this remedy puts a high burden on the regulator and assumes substantial competence on his part to manage the technical needs and assess the right circumstances for intervention. However, the proposed remedy does not require an external regulator to set the price, but is based on the price voluntarily set by a supplier. Furthermore, as noted above, regulators can make use of algorithms to detect price response patterns in the market, to predict and analyze responses to a price freeze, and to determine the optimal length of the price freeze. Indeed, it is high time that we not rely only on human regulation in order to deal with algorithmic coordination. The use of such algorithms might potentially also reduce the risk of regulatory capture, which increases the more complex the regulatory scheme is. Finally, it is possible that in a repeated game the coordinating algorithms. Given these concerns, this solution is more of a thought exercise than a call for action.

Bishop suggested a variation, which is quite similar in spirit.[279] Under his proposal, once supra-competitive pricing is detected, the regulator would freeze a price bid by each oligopolist for a considerable period, one "long enough that any firm bidding prices substantially higher than the lowest bidder would suffer severe losses—and perhaps bankruptcy."[280] Charging a price would then become perilous. To put all firms in the same initial position, the regulator would require each firm to submit its future market price in a secret bid, and would then promulgate the results to take effect on a uniform starting date. Yet such a remedy would require ongoing monitoring of all prices in the market. Also, it would not allow any firm to reduce costs based on productive efficiencies realized during the price freeze (due, for example, to a new innovative production technique), and would not allow firms to react effectively to new market entrants.[281]

Sagi suggested another variation, where an oligopolist that significantly lowers its price would freeze its rivals' prices at their previously higher oligopoly level for a defined period of time ("low-price freeze").[282] As in the high-price freeze remedy suggested above, the anticipation of a low-price

279. William Bishop, *Oligopoly Pricing: A Proposal,* 28 ANTITRUST BULL. 311 (1983); *see also* Paolo Siciliani, *Tackling Algorithmic-facilitated Tacit Collusion in a Proportionate Way* 10 J. EUR. COMPETITION L. & PRACTICE 31 (2018) (suggesting that platform operators impose time restrictions on traders so that they could only change their prices at certain intervals, such as twice a day).

280. Bishop, *supra* note 279, at 315.

281. Gal, *supra* note 262, at 79–80.

282. Sagi, *supra* note 66, at 295–325.

freeze, by itself, might drive prices downward and create an incentive for oligopolists to set ex ante lower prices without the need for actual activation of the price freeze. Additionally, both remedies take advantage of prices set in the market by a firm, rather than requiring the regulator to determine them. Both have some relatively similar downsides. Yet one strong advantage of a low-price remedy is that it freezes the price at the lowest level offered, thereby benefiting the defector, and harming all colluders. As such, it also overcomes the problem of explaining a high price freeze and it gets directly to the low price. Another advantage is that it may overcome the limited capacity problem, given that all firms are now mandated to sell at the mandated low price, regardless of the capacity of the defector. At the same time, a low-price freeze is potentially more interventionary, in the sense that it directly sets the prices for all market participants, rather than for only one. But, more importantly, it might also strengthen concerns that it would lead to long-term inefficiency. One concern is that, if firms are not equally efficient, the defector would set the price at a level that is below the costs of (some of) its competitors.[283] The result might be that some firms would be driven out of the market. Once they do, prices can be returned to higher levels, with less competitors. Such a market structure is not necessarily conducive to welfare, especially if the competitors produce somewhat differentiated products or it changes market conditions so that oligopolistic coordination might be easier to sustain. Furthermore, as Sagi recognizes, the regulator would need to monitor, during the price freeze, all the trade conditions (including quality and non-price competition) of all the firms in the market, but the defector.[284] Moreover, a fixed long-term price of almost all market participants might lead to inefficiency in the face of changing market conditions.[285] Finally, if we assume a multiple period interaction in the market, the motivation to reduce the price also depends on how the potential price reducer expects its rivals to react towards it in a post-freeze world, given that its actions have triggered the regulatory response. Accordingly, the relative efficiency of both types of price freeze remedies depends on what weight should be given to their relative advantages and limitations under different settings.

VI. CONCLUSION

AI-powered pricing algorithms based on technologies like neural networks, deep learning, and reinforcement learning, provide data-driven solutions to cognitive tasks more quickly, and with more sophistication, than

283. For claims that prices can be predatory even if they are above-cost, see Edlin, *supra* note 35.

284. Sagi, *supra* note 66, at 300–01.

285. *Id.* at 300.

human decision-making. Once operated in the digital ecosystem, characterized by speedy communication, price transparency, and in many retail markets also high frequency of trading, such algorithms can change market dynamics and lead to a supra-competitive price equilibrium. They do so without any need for a prior agreement or direct communication. As such, they can be seen as part of what some call the "uncontract" environment, where contractual agreements are supplanted by technology and automatic procedures.[286] As a result, legal assumptions geared to deal with human behavior need to be reexamined. In particular, algorithmic coordination challenges assumptions about the ability of competitors to coordinate without an agreement.

In light of their strong comparative advantages, pricing algorithms are here to stay. Effective regulation is therefore needed to help guide the design, development, and use of such algorithms, in order to minimize their potential risks and maximize their potential benefits for society. Given that research on algorithmic pricing is still in its early stages, regulators should move cautiously. At the same time, it is essential to start thinking seriously about how to deal with algorithmic coordination.

Towards this end, this Article analyzed the current legal status of algorithmic coordination, as well as the main solutions proposed so far. As shown, a straightforward prohibition will not work. Other solutions, while thoughtful and interesting, have significant downsides. Some—like increased transparency—might even increase coordination. Others are highly costly, requiring regulators to maintain an intricate understanding of different types of algorithms in a myriad of market settings. Still others might create harms that exceed the benefits of the proposed regulation. Those solutions are also highly interventionary.

This Article explores four novel solutions, which build upon accumulated economic knowledge about coordinated pricing (e.g., the fact that a coordinated equilibrium is inherently unstable). Two solutions—algorithmic consumers and disruptive algorithms—use algorithms to counter other algorithms, and can be employed by the market as well as by a regulator. The other two solutions—price freezes and merger review—require direct governmental intervention. While three remedies—algorithmic consumers, merger regulation, and disruptive algorithms (operated by market participants)—are a call for action, the price freeze suggestion is more of a thought experiment. We hope this Article prompts more experimentation with the proposed solutions.

286. SHOSHANA ZUBOFF, THE AGE OF SURVEILLANCE CAPITALISM: THE FIGHT FOR A HUMAN FUTURE AT THE NEW FRONTIER OF POWER 218–21 (2019).