DYNAMIC PRICING ALGORITHMS, CONSUMER HARM, AND REGULATORY RESPONSE

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ABSTRACT

Pricing algorithms are rapidly transforming markets, from ride-sharing, to air travel, to online retail. Regulators and scholars have watched this development with a wary eye. Their focus so far has been on the potential for pricing algorithms to facilitate explicit and tacit collusion. This Article argues that the policy challenges pricing algorithms pose are far broader than collusive conduct. It demonstrates that algorithmic pricing can lead to higher prices for consumers in competitive markets and even in the absence of collusion. This consumer harm can be initiated by a single firm employing a superior pricing algorithm. Higher prices arise from the automated nature of algorithms, impacting any market where firms price algorithmically. Pricing algorithms that are already in widespread use may allow sellers to extract a massive amount of wealth from consumers. Because this consumer harm arises even when firms do not collude, antitrust law cannot solve the problem. This Article looks to the history of pricing innovation in the early twentieth century to show how government can respond when new pricing technologies and strategies disrupt markets. It argues for pricing regulation as a feasible solution to the challenges non-collusive algorithmic pricing poses, and it proposes interventions targeted at when and how firms set prices.

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INTRODUCTION

Imagine you are a consumer shopping for over-the-counter allergy medicine online. A search for Allegra, a top brand, leads you to three popular e-commerce websites. One offers a fifteen-pack of Allegra for $17, the second charges $14 for the same pack, and the third asks for $13.[1] All other aspects of the offers being equal, you are of course likely to choose the $13 price. You are also likely to think your research paid off: you got the best deal available and saved some money. The price differences among the retailers might suggest that, by purchasing the lowest-priced offering, you are buying at the "competitive price." But how would you know? What

1. These are the actual prices (rounded to the nearest dollar) for Allegra at three popular e-commerce websites—Target, Walgreens, and Amazon—as of February 1, 2022. All three websites offered free shipping.

if all three retailers are charging above the competitive price? If the retailers used pricing algorithms to set their prices, it is quite possible that this is exactly what happened. Despite the appearance of price competition, you, and every other purchaser of this medicine, paid a supracompetitive price. The retailers used their pricing algorithms to extract wealth from you and your fellow consumers and shift it to themselves.

Pricing algorithms are becoming an increasingly common feature of many markets.[2] Ride-sharing apps,[3] airlines,[4] and Amazon,[5] to name just a few examples, all rely on algorithms to set their prices dynamically. These algorithms are computerized formulas that determine prices automatically based on a set of data inputs.[6] Pertinent data might include competitors' prices, supply and demand conditions, day of the week, and even the personal characteristics of individual purchasers.[7] The advent of pricing algorithms initially seemed to offer the hope of near-perfect competition in online markets. Algorithms give firms the ability to react in real time to their rivals' prices, theoretically sharpening price competition. Combined with the enhanced pricing visibility online shopping offers consumers, pricing

2. *See, e.g.*, Ariel Ezrachi & Maurice E. Stucke, *Artificial Intelligence & Collusion: When Computers Inhibit Competition*, 2017 U. ILL. L. REV. 1775, 1780 (2017) ("Pricing algorithms dominate online sales of goods . . . and are widely used in hotel booking, and the travel, retail, sport, and entertainment industries."); Salil K. Mehra, *Antitrust and the Robo-Seller: Competition in the Time of Algorithms*, 100 MINN. L. REV. 1323, 1324 (2016) ("[Computers'] rising power, plus the growing ubiquity of the Internet, and increasingly sophisticated data-mining techniques have driven a rapid shift of pricing decisions away from human-decision makers in favor of algorithms . . . .").

3. *See How Uber's Dynamic Pricing Model Works*, UBER BLOG, https://www.uber.com/en-GB/blog/uber-dynamic-pricing/ [https://perma.cc/E5HZ-J3CB] (last visited July 17, 2022) (explaining the use of Uber's dynamic pricing algorithm).

4. *See* Tom Chitty, *This Is How Airlines Price Tickets*, CNBC, https://www.cnbc.com/2018/08/03/how-do-airlines-price-seat-tickets.html [https://perma.cc/F64E-BP8P] (Aug. 3, 2018, 12:07 PM) (Airlines' pricing decisions "are being made by an algorithm that adjusts fares by using information including past bookings, remaining capacity, average demand for certain routes and the probability of selling more seats later.").

5. *See* Julia Angwin & Surya Mattu, *Amazon Says It Puts Customers First. But Its Pricing Algorithm Doesn't*, PROPUBLICA (Sept. 20, 2016, 8:00 AM), https://www.propublica.org/article/amazon-says-it-puts-customers-first-but-its-pricing-algorithm-doesnt [https://perma.cc/7KVM-9TFJ] (Amazon uses its "market power and proprietary algorithm to advantage itself at the expense of sellers and many customers.").

6. *See, e.g.*, Michal S. Gal, *Algorithms as Illegal Agreements*, 34 BERKELEY TECH. L.J. 67, 77 (2019) ("Algorithms are structured decision-making processes that automate computational procedures to generate decisional outcomes on the basis of data inputs.").

7. *See, e.g.*, Joseph E. Harrington, Jr., *Developing Competition Law for Collusion by Autonomous Artificial Agents*, 14 J. COMPETITION L. & ECON. 331, 341 (2018) ("A pricing algorithm encompasses a pricing rule which assigns a price to each state," where, "[f]or example, a state could include a firm's cost, inventory, day of the week, and past prices.").

algorithms appeared poised to drive prices down to competitive levels.[8] But this has not happened in many markets.

Compared to traditional pricing methods, algorithms provide sellers with significant advantages. Algorithms can analyze much greater volumes of information in setting prices than human agents, lowering the cost of employing sophisticated pricing strategies.[9] And algorithms can react much more quickly to changing market conditions than human agents, allowing sellers to set the most advantageous prices more of the time.[10]

While pricing algorithms offer significant benefits to sellers, they also raise serious concerns about harm to consumers. In particular, scholars and policy makers worry that firms will employ pricing algorithms to raise prices.[11] Indeed, current scholarship on pricing algorithms' competitive impact has focused almost exclusively on enhanced risks of explicit[12] and tacit collusion,[13] which harm consumers by raising prices and reducing output.

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8. *See, e.g.*, Jeremy Jones, *The Internet: The Perfectly Competitive Market We've Been Waiting For*, YOUNG RSCH. & PUBL'G, INC. (Oct. 10, 2018), https://www.youngresearch.com/researchandanalysis/retail/the-internet-the-perfectly-competitive-market-weve-been-waiting-for/ [https://perma.cc/D9RC-HAGE] ("In economics, perfect competition is sometimes just a theory, but the Internet is bringing that theory closer to reality for retail consumers.").

9. *See, e.g.*, Gal, *supra* note 6, at 79 (A "main advantage of algorithms relates to their analytical sophistication. Advances in data science . . . enable[] algorithms to integrate numerous variables into their decisions," which "provides a level of sophistication that cannot be achieved by the human mind without substantial time and effort.").

10. *See, e.g.*, *id.* at 78–79 ("The most basic advantage [algorithms] offer is speed in the collection, organization, and analysis of data, enabling exponentially quicker decisions and reactions.").

11. *See, e.g.*, Ezrachi & Stucke, *supra* note 2, at 1808 ("Given the transparent nature of these [digitalized] markets, algorithms may change the market dynamics and facilitate tacit collusion, higher prices, and greater wealth inequality."); ORG. FOR ECON. COOP. & DEV., ALGORITHMS AND COLLUSION: COMPETITION POLICY IN THE DIGITAL AGE 34 (2017), https://www.oecd.org/daf/competition/Algorithms-and-colllusion-competition-policy-in-the-digital-age.pdf [https://perma.cc/6PTE-JHQB] ("[A]lgorithms may make firms' actions interdependent without the need for explicit communication or interaction, increasing thereby the risk of tacit collusion and subsequently leading to higher price levels.").

12. *See* Ezrachi & Stucke, *supra* note 2, at 1784–89 (discussing the use of pricing algorithms to facilitate price-fixing conspiracies); Harrington, *supra* note 7, at 360 ("If autonomous cars can navigate city roads and traffic, is it that difficult to imagine autonomous artificial agents figuring out how to collude? Can we really be so sure that collusion by autonomous artificial agents will never be commonplace?"). The Department of Justice has already uncovered a scheme among rival firms to use pricing algorithms to fix prices. *See* Press Release, U.S. Dep't of Just., Antitrust Div., 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 [https://perma.cc/J6P9-3XDY] (describing guilty plea in case involving use of pricing algorithms to fix prices for the sales of posters on the Amazon Marketplace).

13. *See, e.g.*, Ai Deng, *What Do We Know About Algorithmic Tacit Collusion?*, 33 ANTITRUST 88, 88 (2018) ("[T]here is growing experimental evidence that an algorithm can be designed to tacitly collude."). Unlike price fixing, tacit collusion does not involve an explicit agreement among competing firms. Instead, firms establish a collusive, supracompetitive price by observing their rivals' prices and

This Article breaks new ground by identifying a distinct form of consumer harm that arises from the use of pricing algorithms in competitive markets, analyzing the legal ramifications of this algorithmic harm, and proposing policy responses. It builds on pioneering theoretical and empirical scholarship in economics by one of the authors (MacKay) and Zach Brown, which demonstrates that competition among pricing algorithms allows firms to charge consumers supracompetitive prices *even in the absence of collusion*.[14] These effects are driven by standard features of algorithms that are already in widespread use, including at the largest online retailers, such as Amazon[15] and Walmart.com.[16] Unlike algorithmic collusion, which requires some measure of coordination among firms to raise prices, the harms we identify can be initiated by a single firm employing a superior algorithm. Because it is likely to affect most markets where prices are set algorithmically, this threat to consumer well-being is in some respects more serious than that posed by explicit or tacit algorithmic collusion, which require more stringent market conditions to be

reaching an unspoken understanding that any deviations from the collusive price will be met by immediate retaliatory price cuts. Pricing algorithms facilitate tacit collusion by increasing the speed and reliability with which firms can observe and react to rivals' prices. *See* ORG. FOR ECON. COOP. & DEV., *supra* note 11, at 51 ("[B]y providing companies with powerful automated mechanisms to monitor prices, implement common policies, send market signals or optimise joint profits with deep learning techniques, algorithms might enable firms to achieve the same outcomes of traditional hard core cartels through tacit collusion.").

14. *See* Zach Y. Brown & Alexander MacKay, *Competition in Pricing Algorithms*, 14 AM. ECON. J.: MICROECONOMICS (forthcoming), https://www.hbs.edu/ris/Publication%20Files/20-067_21e2440e-751b-4d03-a5e7-653570aa1e75.pdf [https://perma.cc/BM5E-BM8D].

15. Amazon competes in a variety of markets, including e-commerce, cloud computing services, advertising, entertainment, autonomous vehicles, and groceries. *See* Meaghan Yuen, *Amazon Annual Revenue Breakdown by Segment in 2022*, INSIDER INTEL. (Feb. 11, 2022), https://www.insiderintelligence.com/insights/amazon-revenue/ [https://perma.cc/5PL3-CVQV] (listing Amazon's revenues by segment, including e-commerce, cloud services, advertising, subscriptions, and brick-and-mortar stores). This Article uses "Amazon" to refer to the company's e-commerce business, Amazon.com. The "Amazon Marketplace" is Amazon's e-commerce platform for third-party sellers. Amazon also sells its own goods on Amazon.com, often competing with sellers on the Amazon Marketplace. *See* Le Chen, Alan Mislove & Christo Wilson, *An Empirical Analysis of Algorithmic Pricing on Amazon Marketplace*, *in* WWW '16: PROCEEDINGS OF THE 25TH INTERNATIONAL CONFERENCE ON WORLD WIDE WEB 1339, 1340 (International World Wide Web Conferences Steering Committee, Republic and Canton of Geneva, Switzerland 2016).

16. *See* Chris Walton, *5 Things the Top 10 Online U.S. Retailer List Says About the Future*, FORBES (May 18, 2021, 9:43 AM), https://www.forbes.com/sites/christopherwalton/2021/05/18/5-things-the-top-10-online-us-retailer-list-says-about-the-future/?sh=2de1c1536ef4 (listing the top ten online retailers by estimated 2021 sales, with Amazon ($367.19 billion) and Walmart ($64.62 billion) numbers one and two); Kim Souza, *The Supply Side: Avoiding the Race to the Bottom with Online Pricing Algorithms*, TALK BUS. & POL. (Feb. 22, 2018), https://talkbusiness.net/2018/02/the-supply-side-avoiding-the-race-to-the-bottom-with-online-pricing-algorithms/ (discussing Amazon's and Walmart's algorithmic pricing).

successful.[17] The legal means to address algorithms' competitive price effects is the central focus of this Article.

Pricing algorithms facilitate supracompetitive pricing in competitive markets in two ways. First, they allow some firms to update prices faster than other firms.[18] For example, a firm with an advanced pricing algorithm might be able to reprice its goods every day or even multiple times per day, while a firm with a less sophisticated algorithm might be able to re-price only once a week. Typically, the firm with a faster algorithm will have a competitive advantage, as it will be able to undercut the price of a rival without a commensurate response.[19] The slower firm can perceive the ability of the faster firm to quickly reduce prices as a threat, limiting its incentives to compete on price.[20] The slower firm will charge a price above the competitive level, understanding that it will lose some customers to its faster rival.[21] The faster rival then chooses a price below its rival's price yet above the competitive level, taking share from the rival while also capturing supracompetitive margins.[22] The result of this *asymmetric frequency* is that both firms will charge above the competitive price and consumers will pay more for goods than they did before.[23]

A second way in which pricing algorithms lead to higher prices is through a commitment to pre-specified pricing strategies.[24] Algorithms typically encode in software a set of instructions to update prices, and this software is used to update prices many times before the instructions are changed.[25] In this way, the algorithm allows a firm to commit to a pricing strategy in advance. Just as a faster algorithm provides a firm with a threat to undercut slower rivals, an algorithm that can autonomously observe and

17. *See* Ariel Ezrachi & Maurice E. Stucke, *Sustainable and Unchallenged Algorithmic Tacit Collusion*, 17 NW. J. TECH. & INTELL. PROP. 217, 226 (2020) ("Algorithmic tacit collusion . . . will not affect every (or even most) markets."). Collusion, whether explicit or tacit, is likely to be sustainable only in highly concentrated markets featuring, among other characteristics, homogenous products, transparent pricing, and high barriers to entry. *See, e.g.*, Deng, *supra* note 13, at 92 (listing "the structural characteristics that tend to facilitate/disrupt collusion").

18. *See* Brown & MacKay, *supra* note 14, at 1 (describing empirical evidence showing that e-commerce retailers use algorithms to "update prices at regular intervals, but these intervals differ across firms, allowing some retailers to adjust prices at higher frequencies than their rivals").

19. *See id.* at 2 (describing empirical evidence showing that firms with faster algorithms "quickly react to price changes by slower rivals, consistent with the use of automated pricing algorithms that monitor rivals' prices and follow a pre-specified strategy").

20. *See id.* at 3 (arguing that when firms with superior pricing technology commit to undercutting prices of their slower rivals, "[t]he rivals take this into account, softening price competition").

21. *See id.* at 25 ("This softens firm 1's incentive to compete on price. . . . Firm 1 loses market share to firm 2 . . . but profits are . . . higher for both firms . . . .").

22. *Id.*

23. *Id.* at 1 ("If one firm adopts superior [pricing] technology, all firms can obtain higher prices.").

24. *Id.* at 7 ("[A]n algorithm provides a short-run commitment device to a pricing strategy.").

25. *Id.*

react to competitors' price changes gives a firm an advantage relative to one that lacks this technology.[26] When firms with superior technology commit to this strategy, firms with inferior technology know that their rivals can be relied on to undercut their prices.[27] In this *asymmetric commitment* scenario, as with asymmetric frequency, all firms will charge above the competitive price.[28] In both scenarios, higher prices can reduce output and total welfare in addition to generating consumer harm.[29]

While the firms in these scenarios are charging supracompetitive prices, it is important to emphasize that they are not colluding.[30] Collusion—explicit or tacit—requires each firm to make short-run sacrifices for long-run gains. Antitrust enforcement against collusion is predicated on finding an agreement among firms to encourage such short-run sacrifices.[31] We focus instead on settings in which all firms act non-cooperatively to pursue their own rational self-interest; therefore, no agreement is necessary. Further, key characteristics distinguish collusive regimes from algorithmic competition. In a market subject to collusion, we would expect firms to charge similar prices and to engage in a reward-punishment regime to discipline price-cutters.[32] In such regimes, a single price cut is punished by an extended period of even more drastic price cuts by rivals, reducing the profits of all firms.[33] Neither similar prices nor reward-punishment schemes are necessary, or even expected, in the markets we describe. Notably—like in the allergy medicine example above—firms may be charging quite different prices, yet all prices are higher than what consumers would pay in

26. *Id.* at 23 (Proposition 3).

27. *Id.* at 23–24. ("[T]he asymmetric commitment game obtains an identical equilibrium to the asymmetric frequency game . . . .").

28. *Id.* at 24 ("[A]symmetries in pricing technologies are sufficient to generate higher prices than those in the simultaneous price-setting equilibrium.").

29. *Id.* at 40 (predicting that algorithmic competition results in a "modest" reduction in output, a "small" decline in total welfare, and a significant transfer of wealth from buyers to sellers).

30. Jonathan Baker and Joseph Farrell have identified a category of non-collusive oligopoly conduct, what they term "nonpurposive conduct," that can result in higher consumer prices. *See* Jonathan B. Baker & Joseph Farrell, *Oligopoly Coordination, Economic Analysis, and the Prophylactic Role of Horizontal Merger Enforcement*, 168 U. PA. L. REV. 1985, 1998 (2020) ("When oligopolists respond to one another's price changes in a natural business way, they are engaged in nonpurposive strategic conduct. Although those reactions are not part of an express scheme or an informal effort to develop a common understanding or deter price-cutting, those predictable responses will generally affect oligopolists' incentives and may well discourage price-cutting.").

31. *See In re* Text Messaging Antitrust Litig., 782 F.3d 867, 879 (7th Cir. 2015) ("Collusion is illegal only when based on agreement.").

32. *See, e.g.*, Harrington, *supra* note 7, at 336 ("*Collusion* is when firms use strategies that embody a reward-punishment scheme which rewards a firm for abiding by the supracompetitive outcome and punishes it for departing from it.").

33. *See* Christopher R. Leslie, *Judgment Sharing Agreements*, 58 DUKE L.J. 747, 781 (2009) ("[C]heating can destabilize a cartel, resulting in price wars in which all firms are worse off than if every firm had abided by the cartel price.").

a competitive market.[34] Perhaps the most significant difference between algorithmic collusion and the model we describe here is that a single firm can initiate a cycle of consumer harm simply by employing a superior pricing algorithm. Several firms—Amazon included—already price using algorithms that are superior to their rivals' pricing technologies.[35]

Moreover, an observer may naturally think that algorithms—which enhance the ability of firms to react to rivals' prices—would intensify competition, but the reverse is true. These theoretical models indicate that the increasing use of pricing algorithms will lead to higher prices for consumers, even when firms are unable to collude. This conclusion is buttressed by empirical evidence showing that algorithmic pricing and asymmetric pricing frequency are already leading to higher prices in certain e-commerce markets.[36]

This trend is concerning because algorithmic pricing is spreading quickly throughout the economy.[37] In addition to the proprietary algorithms that firms like airlines, ride-sharing companies, and hotel chains employ to set their prices, there has been explosive growth in the development of third-party pricing algorithms that firms can purchase and use to set their pricing strategies.[38] These developments are significantly affecting retail pricing,

34. Brown & MacKay, *supra* note 14, at 2 (finding average price differences for identical products exceeding twenty-five percent between the firm with the fastest algorithm and those with the slowest).

35. *See infra* note 68.

36. *See* Brown & MacKay, *supra* note 14, at 2 (reporting findings from empirical study tracking the pricing of five online retailers of over-the-counter allergy drugs and showing that variability in sophistication of pricing algorithms led to asymmetric pricing frequency, resulting in meaningful price increases above the competitive level in that market).

37. *See* ORG. FOR ECON. COOP. & DEV., *supra* note 11, at 3 ("[A] growing number of firms are using computer algorithms to improve their pricing models, customise services and predict market trends."); Emilio Calvano, Giacomo Calzolari, Vincenzo Denicolò & Sergio Pastorello, *Artificial Intelligence, Algorithmic Pricing and Collusion*, 110 AM. ECON. REV. 3267, 3267 (2020) ("Software programs are increasingly being adopted by firms to price their goods and services, and this tendency is likely to continue."); Ivan Zhou, *AI-Powered Dynamic Pricing Is Everywhere*, SYNCEDREVIEW (Nov. 24, 2018), https://medium.com/syncedreview/ai-powered-dynamic-pricing-is-everywhere-4271a9939d11 [https://perma.cc/N4EH-TQCX] ("[A]lgorithmic dynamic pricing is transforming transportation, E-commerce, entertainment, and a wide range of other industries.").

38. *See* COMPETITION & MKTS. AUTH., PRICING ALGORITHMS: ECONOMIC WORKING PAPER ON THE USE OF ALGORITHMS TO FACILITATE COLLUSION AND PERSONALISED PRICING 3 (2018), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/746353/Algorithms_econ_report.pdf [https://perma.cc/UK87-ZRE2] ("As well as simple pricing rules provided by the platforms themselves, some third-party firms sell more sophisticated pricing algorithms to retailers or directly take on the role of pricing using computer models on behalf of their clients."); *See, e.g.*, Chen et al., *supra* note 15, at 1339 ("Travel websites and large, well known e-retailers have already adopted algorithmic pricing strategies, but the tools and techniques are now available to small-scale sellers as well.").

particularly in e-commerce.[39] Many of the third-party algorithms that firms use are targeted at helping sellers win business on the Amazon Marketplace.[40] Already some empirical evidence has demonstrated that increasing numbers of merchants are employing pricing algorithms on Amazon and that these merchants win more sales than sellers using traditional pricing methods.[41]

When pricing technologies distort markets, what is the appropriate response? The remedy for explicit algorithmic collusion is obvious: antitrust enforcement. Price fixing is per se illegal and a criminal offense under section 1 of the Sherman Act.[42] That rule should apply whether price fixing is agreed upon and executed over the phone or through an algorithm. More challenging cases arise when the algorithm is not explicitly programmed to collude and does so on its own via communication with other algorithms. But in the standard case, human agents will have agreed to use their algorithms to fix prices, and Sherman Act liability will attach.

Tacit collusion is a more difficult problem to remedy. Because there is no explicit agreement in a tacit collusion scenario, section 1 of the Sherman Act would not apply under current law.[43] Scholars and policy makers have suggested expanding antitrust law to capture tacit collusion, for example, by

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39. *See, e.g.*, Chen et al., *supra* note 15, at 1348 (noting that certain "algorithmic sellers change prices tens or even hundreds of times per day, which would be difficult for a human to maintain over time"); Ilya Katsov, *Algorithmic Pricing, Part 1: The Risks and Opportunities*, GRID DYNAMICS (Dec. 11, 2018), https://blog.griddynamics.com/algorithmic-pricing-part-i-the-risks-and-opportunities/ [https://perma.cc/U6UP-32WX] ("Algorithmic pricing technologies and the transparency of the Internet have had a major impact on the pricing behavior of retailers and even the US economy as a whole.").

40. *See, e.g.*, *Amazon Repricing Features That Get You the Buy Box*, REPRICER.COM, https://www.repricer.com/features [https://perma.cc/4AXF-PTXN] (promotional material from a third-party algorithm software vendor promising that users can "[c]ompete on Amazon your way with flexible, targeted rules"); Jessica Leber, *Algorithmic Pricing Is Creating an Arms Race on Amazon's Marketplace*, FAST CO. (June 14, 2016), https://www.fastcompany.com/3060803/algorithmic-pricing-is-creating-an-arms-race-on-amazons-marketplace ("In the last few years, some startups have made it easy for even small sellers to use algorithmic pricing on Amazon's marketplace with their own custom criteria.").

41. *See* Chen et al., *supra* note 15, at 1339–40 (describing dataset including sellers of around 1,600 "best-seller products" on the Amazon Marketplace, identifying in that dataset "over 500" sellers using algorithmic pricing, and concluding that such sellers are more successful than non-algorithmic sellers).

42. *See* U.S. DEP'T OF JUST., PRICE FIXING, BID RIGGING, AND MARKET ALLOCATION SCHEMES: WHAT THEY ARE AND WHAT TO LOOK FOR 1–2 (2021), https://www.justice.gov/atr/file/810261/download [https://perma.cc/8R8D-RLBF] ("[P]rice-fixing and bid-rigging schemes are per se violations of the Sherman Act" and "are subject to criminal prosecution by the Antitrust Division of the United States Department of Justice.").

43. *See In re* Text Messaging Antitrust Litig., 782 F.3d 867, 879 (7th Cir. 2015) ("Tacit collusion . . . does not violate section 1 of the Sherman Act. Collusion is illegal only when based on agreement."). This situation is different in the European Union, where under section 102 of the Treaty of Functioning of the European Union (TFEU), liability for tacit collusion can be characterized as an "abuse of dominance." *See* Ariel Ezrachi & Maurice E. Stucke, *Algorithmic Collusion: Problems and Counter-Measures*, ORG. FOR ECON. COOP. & DEV. 19 n.61 (2017) ("Tacit collusion may serve to establish Collective Dominance under Article 102 TFEU, but absent a separate abuse, it will also escape scrutiny under this provision.").

broadening what qualifies as an "agreement" for purposes of section 1, or, more simply, by prohibiting tacit collusion altogether.[44] Regulation is another possibility, including restrictions on how algorithms operate and direct price regulation of markets subject to tacit collusion.[45]

The problem this Article addresses—non-collusive algorithmic pricing leading to higher consumer prices—is likely both more common than explicit or tacit collusion and more difficult to remedy. Because, by definition, we are focusing on competitive markets where firms are not colluding, this conduct is beyond the current reach of antitrust law, even broadly defined.[46] How can governments address new harms arising from technology that fall outside traditional bounds of enforcement? Regulation is one potential solution.

Pricing regulation has at best a checkered reputation among economists and policy makers.[47] But it remains a viable option when market conditions warrant, and we argue that the consumer harm algorithmic pricing will cause can be addressed by regulatory intervention. This would not be the first time that advances in pricing technologies have triggered a regulatory response. In the early twentieth century, price display innovations, including price cards and price-card holders, led to a sea change in retail markets.[48] Suddenly, retailers gained the ability to easily advertise prices to consumers and to change those prices quickly by replacing a price or quantity card. These technologies led to the development of new pricing strategies, including batch pricing (e.g., four fifty-cent items for a dollar) and loss leaders.[49] Before this technological revolution, retailers set prices on an ad hoc basis for each buyer, based on the seller's costs and other variables.[50]

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44. *See, e.g.*, Gal, *supra* note 6, at 117 (arguing, in light of the threat of algorithmic tacit collusion, that "the time may be ripe to reconsider prohibiting any conduct with potential anticompetitive tendencies with no offsetting pro-competitive ones, even where such conduct does not constitute an agreement in the traditional sense").

45. *See, e.g.*, Ezrachi & Stucke, *supra* note 2, at 1806–07 (detailing options for responding to tacit algorithmic collusion, including "an *ex ante* approach by which, under certain market conditions, companies must report the use of certain algorithms" and "price regulation" powered by "Big Data and Big Analytics").

46. Certain forms of non-collusive pricing conduct sometimes can violate the antitrust laws, including pricing below cost (predatory pricing), resale price maintenance, and price discrimination. *See infra* Section III.A. But none of these causes of action apply to non-collusive algorithmic pricing resulting in higher prices. *See id.*

47. *See, e.g.*, Hugh Rockoff, *Price Controls*, *in* THE CONCISE ENCYCLOPEDIA OF ECONOMICS 409, 409 (David R. Henderson ed., 2008) ("[E]conomists are generally opposed to [price controls].").

48. *See* Franck Cochoy, Johan Hagberg & Hans Kjellberg, *The Technologies of Price Display: Mundane Retail Price Governance in the Early Twentieth Century*, 47 ECON. & SOC'Y 572, 579–80 (2018) (describing the development of "new price tag devices" in the 1920s and its effect on retail pricing); *see also infra* Section III.B.1.

49. Cochoy et al., *supra* note 48, at 580–86.

50. *Id.* at 577.

Now, prices were generally the same for all buyers and comparison shopping became possible, forcing retailers for the first time to routinely take their rivals' prices into account when setting price.[51] The result was a period of intense price-cutting and deflation leading up to and during the Great Depression.[52]

Policy makers proposed several different market interventions to address the deflationary effect of these pricing innovations, culminating in the industrial codes authorized by the National Industrial Recovery Act of 1933 (NIRA).[53] The NIRA permitted industry organizations to propose "codes of fair competition," which instituted price floors and restricted price cutting.[54] Once approved by the federal government, these codes were exempted from the antitrust laws.[55] A number of scholars have argued that the Roosevelt administration's decision essentially to suspend the antitrust laws to control deflation was a mistake.[56] But this episode demonstrates how advances in pricing technologies can destabilize markets and the potential for government to respond with broad price regulation.

While policy makers in the 1920s and 1930s were faced with pricing innovations that led to what they viewed as ruinous price cutting, current innovations in algorithmic pricing instead can result in significant price increases for consumers.[57] Any regulatory intervention would be aimed at forcing prices back to competitive levels. One candidate is to use price controls to directly reduce prices in markets subject to algorithmic pricing. We oppose this solution as too disruptive, expensive, and overbroad. Price controls have proved in the past to be ineffective over the long term and to lead to undesirable outcomes like surpluses of goods whose price is set too high and shortages of goods whose price is set too low.[58] Further, because the shift to algorithmic pricing is a long-term trend that affects many different products, any price-control regime would involve establishing a

51. *Id.* at 577–79.

52. *Id.* at 574 (arguing that the implementation of price-cutting strategies after World War I "led to the development of price wars that worsened the effect of the Great Depression").

53. National Industrial Recovery Act, Pub. L. No. 73-67, 48 Stat. 195 (1933), *invalidated by* A.L.A. Schechter Poultry Corp. v. United States, 295 U.S. 495 (1935).

54. *Id.* tit. 1, § 3.

55. *Id.* § 5.

56. *See, e.g.*, Christina D. Romer, *Why Did Prices Rise in the 1930s?*, 59 J. ECON. HIST. 167, 197 (1999) (arguing that the NIRA "prevented the economy's self-correction mechanism from working" and that "the NIRA can best be thought of as a force holding back recovery").

57. *See supra* notes 34 & 36.

58. *See* Fiona M. Scott Morton, *The Problems of Price Controls*, 24 REGULATION 50, 52 (2001) (describing the "worrisome history of price controls" and arguing that "these policies . . . still lead to serious problems for producers and consumers"); Rockoff, *supra* note 47, at 409 ("Price ceilings, which prevent prices from exceeding a certain maximum, cause shortages. Price floors, which prohibit prices below a certain minimum, cause surpluses, at least for a time.").

huge new bureaucracy and fundamentally altering the relationship between the federal government and the market.

We advocate instead a more surgical intervention to promote competition: using regulation to limit key features of algorithms, without requiring detailed knowledge of the calculations that algorithms perform or what the competitive price levels might be. The mechanisms by which pricing algorithms raise prices even in the absence of collusion—asymmetric pricing frequency and commitment to react to rivals' prices in a pre-specified way—suggest the forms this regulation could take.[59] One approach would be to prohibit asymmetric pricing frequency by requiring firms to price at the same time and on the same schedule, say once a day at 6 a.m.[60] This reform would eliminate the possibility of the type of leader-follower conduct that results in all sellers in a market charging supracompetitive prices. It would also be a relatively administrable reform because it would not require a regulator to evaluate individual firms' algorithms. The regulator's task simply would be to ensure that firms are pricing only at authorized times. A potential downside to this reform is that it would prevent firms from reacting quickly to changes in market conditions. And it is possible that requiring firms to price at the same time would make it easier for firms to collude.[61]

A second option is a rule prohibiting firms from incorporating rivals' prices into their algorithms.[62] This intervention would prevent superior algorithms from automatically undercutting prices set by inferior algorithms, disrupting the leader-follower pattern that would otherwise develop. Further, it would allow firms to re-price whenever and as often as they want, so firms could react quickly to changes in market conditions (other than changes in rivals' prices). Algorithms still would have significant amounts of data to work with, including supply and demand conditions, seasonal conditions, and customer characteristics.

Regulation barring firms from using competitors' prices as algorithmic inputs would be more challenging to administer than rules restricting when firms can set prices. To ensure compliance, a new bureaucracy likely would have to be created to review each individual pricing algorithm. Another

59. *See supra* notes 18–23 and accompanying text.

60. *See infra* Section III.C.1.

61. *See* Ralf Dewenter & Ulrich Heimeshoff, *Less Pain at the Pump? The Effects of Regulatory Interventions in Retail Gasoline Markets* 4 (Düsseldorf Inst. for Competition Econ., Discussion Paper No. 51, 2012), https://www.dice.hhu.de/fileadmin/redaktion/Fakultaeten/Wirtschaftswissenschaftliche_Fakultaet/DICE/Discussion_Paper/051_Dewenter_Heimeshoff.pdf [https://perma.cc/W6AB-H26Q] (describing experimental studies predicting that Austrian and Western Australian retail gas pricing regulations that limit when firms are allowed to price would increase the likelihood of collusion and lead to higher prices).

62. *See infra* Section III.C.2

drawback to this approach is that it may make it more difficult for some firms to compete aggressively on price. In a healthy market, firms are expected to compete on multiple fronts—including quality and product variety—but price competition is especially important.[63] Consumers typically benefit from this competition by paying less for their goods and services. Restrictions that limit automated responses to rivals' price shifts therefore may be perceived as dulling price competition. However, these restrictions are likely to have only short-run effects on competition. Over longer periods, firms can adjust the parameters governing their algorithms to deliver lower price levels and compete more effectively, without relying on automated responses to rivals' prices.

One shared risk of these two regulatory regimes is that they might dull incentives to innovate in algorithmic pricing. If firms are restricted from pricing more than once a day, for example, the incentive to produce faster algorithms is reduced. But, if innovation in pricing algorithms harms consumers, should we care about these dulled incentives? We think not. Pricing algorithms can harm consumers, even in competitive markets. They are what we term an "extractive innovation," which we define as any technological advance that harms rather than helps consumers by transferring wealth from consumers to firms. Such innovations result in lower consumer welfare—in this case, by raising prices without an increase in product quality, as it is not clear that consumers receive any meaningful benefit from high-frequency price changes in online retail. Regulators' approach to innovative but dangerous products—flavored e-cigarettes that appeal to young consumers, for example—provides a useful example of how to treat extractive innovation: mitigate risks through targeted regulation.[64] In sum, when they identify extractive innovations, courts, enforcers, and regulators should be less concerned about policies that reduce related innovation incentives. Indeed, they should consider ways to discourage additional innovative harm.

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63. *See* FED. TRADE COMM'N, COMPETITION COUNTS: HOW CONSUMERS WIN WHEN BUSINESSES COMPETE 1 https://www.ftc.gov/system/files/attachments/competition-counts/pdf-0116_competition-counts.pdf [https://perma.cc/3GD5-UYN6] ("Competition in America is about price, selection, and service. It benefits consumers by keeping prices low and the quality and choice of goods and services high."). Economic theory predicts that sophisticated firms are able to anticipate the actions of rivals and attain competitive price levels, even when not observing those actions directly. *See, e.g.*, Dale O. Stahl & Paul W. Wilson, *On Players' Models of Other Players: Theory and Experimental Evidence*, 10 GAMES AND ECON. BEHAVIOR 218, 220–21 (1995). In practice, a restriction that prevents firms from incorporating rivals' prices into algorithms could soften price competition and yield higher prices in some situations.

64. *See* U.S. DEP'T OF HEALTH & HUM. SERVS., FOOD & DRUG ADMIN., CTR. FOR TOBACCO PRODS., ENFORCEMENT PRIORITIES FOR ELECTRONIC NICOTINE DELIVERY SYSTEMS (ENDS) AND OTHER DEEMED PRODUCTS ON THE MARKET WITHOUT PREMARKET AUTHORIZATION (REVISED) 3 (Apr. 2020) (The "FDA intends to prioritize enforcement against [a]ny flavored, cartridge-based ENDS product.").

Both the potential interventions we consider—regulating *when* firms price or *how* they price—have significant advantages and disadvantages. Today, requiring firms to adjust prices at the same time and at the same interval seems the less intrusive, less expensive, and superior intervention for most markets subject to algorithmic pricing competition. But that could change as pricing technology develops and more empirical evidence about the effects of algorithmic pricing emerges.

The Article is presented in three Parts. Part I surveys the use of pricing algorithms in practice, including how these algorithms work and the markets in which they are currently being used. This Part also describes current scholarly approaches to algorithmic pricing, which focus almost exclusively on its facilitation of explicit and tacit collusion. Part II applies game theory to describe the effects of pricing algorithms in competitive markets. It demonstrates that algorithmic pricing will lead to supracompetitive prices even in the absence of collusion, and it discusses empirical evidence of these effects. Part III addresses potential policy responses to the consumer harm pricing algorithms cause in competitive markets. This Part argues that there is no practical antitrust solution to this problem and that a regulatory response will be necessary. It proposes and analyzes two regulatory approaches to the challenges pricing algorithms pose: restricting when firms price and whether their algorithms can incorporate competitors' prices.

I. PRICING ALGORITHMS IN PRACTICE

Evaluating the scope and seriousness of the effects of algorithmic pricing on consumers requires understanding how pricing algorithms currently operate in practice. To this end, this Part describes the different types of pricing algorithms firms employ and the sectors where their effects are most likely to be felt. It also surveys the growing body of scholarly literature on algorithmic pricing.

A. Function and Relevant Markets

The use of pricing algorithms is exploding, particularly in e-commerce.[65] While their sophistication varies, pricing algorithms all function in the same general manner: they automatically apply a computerized rule to set prices based on various inputs. These inputs commonly include demand for and

65. *See, e.g.*, Calvano et al., *supra* note 37, at 2 ("Firms are increasingly adopting software algorithms to price their goods and services."); Zhou, *supra* note 37 ("[A]lgorithmic dynamic pricing is transforming transportation, E-commerce, entertainment, and a wide range of other industries.").

supply of specific products, competitors' prices, customer demographics and preferences, time of day, day of the week, and time of year.[66] Pricing algorithms allow firms, particularly e-commerce firms, to quickly and continually update and optimize their pricing.

Algorithmic pricing is not a new technology. The major airlines have used pricing algorithms to set their prices for many years.[67] But the development of Internet-based commerce and the advent of increasingly advanced computing equipment, combined with the availability of tremendous amounts of consumer data, have increased the power and reach of these algorithms. Many sophisticated firms have developed their own proprietary pricing algorithms. Uber and Lyft are well-known examples of companies whose business models are based on algorithms that continually reprice in response to changes in demand and supply conditions.[68] These companies are able to take advantage of the huge amounts of customer data they collect to adjust prices on the fly as conditions warrant.[69] The airlines continue to use their proprietary pricing algorithms to finely adjust ticket prices for different routes, different days of the week and times of day, and even for different travelers.[70] Hotel chains and rental car companies do the same.[71] Large online retailers like Walmart and eBay also employ proprietary algorithms on their e-commerce platforms.[72]

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66. *See, e.g.*, Ezrachi & Stucke, *supra* note 2, at 1780 ("Pricing algorithms . . . optimiz[e] the price based on available stock and anticipated demand . . . ."); Harrington, *supra* note 7, at 341 ("A pricing algorithm encompasses a pricing rule which assigns a price to each state. For example, a state could include a firm's cost, inventory, day of the week, and past prices.").

67. *See* R. Preston McAfee & Vera L. te Velde, *Dynamic Pricing in the Airline Industry*, *in* 1 HANDBOOKS IN INFORMATION SYSTEMS: ECONOMICS AND INFORMATION SYSTEMS 527, 527 (Terrence Hendershott ed., 2006) ("The initial development of dynamically adjusted pricing is often credited to American Airlines' Robert Crandall, as a response to the rise of discount airline People's Express in the early 1980s.").

68. *See* Zhou, *supra* note 37 (describing Uber's and Lyft's "real-time dynamic pricing" and how their algorithms respond to driver supply and customer demand data); UBER BLOG, *supra* note 3.

69. *See* Zhou, *supra* note 37 ("Uber and Lyft are evolving the [dynamic pricing] concept by leveraging their massive data in real time.").

70. *See* David Kreighbaum Jr., *Algorithms Take Flight: Modern Pricing Algorithms' Effect on Antitrust Laws in the Aviation Industry*, 32 LOY. CONSUMER L. REV. 282, 289 (2020) (explaining that airlines adjust their prices based on type of customer, "time of day and week," and specific route).

71. *See* Cem Dilmegani, *Dynamic Pricing: What It Is, Why It Matters & Top Tools in 2022*, AI MULTIPLE, https://research.aimultiple.com/dynamic-pricing/ [https://perma.cc/TUE8-VZ3W] (Feb. 10, 2022) (explaining the use of dynamic pricing in the hospitality and car rental industries).

72. *See* Suman Bhattacharyya, *Pressured by Amazon, Retailers Are Experimenting with Dynamic Pricing*, DIGIDAY (Feb. 21, 2019), https://digiday.com/retail/amazon-retailers-experimenting-dynamic-pricing/ [https://perma.cc/7TSP-J4TH] ("Walmart had to 'change its religion' of everyday low prices for dynamic pricing to compete with Amazon . . . ."); Shreya Raval, *eBay Makes Search More Efficient Through Personalization*, EBAY (June 23, 2020), https://tech.ebayinc.com/product/ebay-makes-search-more-efficient-through-personalization/ [https://perma.cc/PH6L-PM4C] (describing eBay's "efforts to enhance [its] machine learning algorithms to improve the quality of search results for buyers," and explaining eBay's "price propensity" feature, which "customize[s] the search results based on a user's price preference" by taking "into consideration a user's past purchases at eBay.").

Amazon, which surpassed forty percent of all e-commerce revenues in 2021,[73] employs a dynamic pricing algorithm for its products. Analysts have asserted that Amazon changes its prices 2.5 million times a day.[74] Amazon's pricing algorithm takes advantage of the company's trove of customer and competitor data, incorporating customer preferences, rivals' prices, product supply, and many other criteria in setting prices.[75]

Amazon is an enormous company with the resources to develop a sophisticated algorithm. But firms no longer need to invest in creating their own algorithms to take advantage of this pricing technology. Third-party vendors sell pricing algorithms that even small firms can use to customize their pricing.[76] These third-party algorithms are transforming Internet retail, making it much more likely that consumers will purchase products that algorithms have priced. Companies like Repricer.com, 5Analytics, and antuit.ai provide off-the-shelf algorithmic pricing tools for retailers.[77] Repricer.com promises that its solution will allow sellers to "[b]eat competitors with super-fast repricing,"[78] while Antuit claims that its price optimization tools can "[s]imulate the impact of competitors' price moves against your prices" and "[b]uild price/pack architectures balancing market sensitivity, volume, profit, and revenue."[79]

Third-party providers offer various strategies or "modules" to customize pricing algorithms. For example, a "key-value-items module" (KVI) focuses on pricing those items that significantly affect customers' general

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73. Stephanie Chevalier, *Market Share of Leading Retail E-Commerce Companies in the United States as of October 2021*, STATISTA (Oct. 13, 2021) https://www.statista.com/statistics/274255/market-share-of-the-leading-retailers-in-us-e-commerce/ [https://perma.cc/L7VT-MQ42].

74. *See, e.g.*, Neel Mehta, Parth Detroja & Aditya Agashe, *Amazon Changes Prices on Its Products About Every 10 Minutes – Here's How and Why They Do It*, BUS. INSIDER (Aug. 10, 2018, 10:13 AM), https://www.businessinsider.com/amazon-price-changes-2018-8 [https://perma.cc/WDV8-K569].

75. *Id.*

76. *See* Chen et al., *supra* note 15, at 1339 ("[T]he tools and techniques" to adopt algorithmic pricing strategies "are now available to small-scale sellers as well.").

77. *See Lifecycle Pricing*, ANTUIT.AI, https://www.antuit.ai/solutions/retail/life-cycle-pricing [https://perma.cc/XY7P-HK56] (last visited July 17, 2022) (explaining the advantages of antuit.ai's "Lifecycle Pricing"); *Beat Your "Buy It Now" Competitors with Our Super-Fast eBay Repricer*, REPRICER.COM, https://www.repricer.com/ebay-repricer [https://perma.cc/S5FF-KPAB] (last visited July 17, 2022) ("Join the 5,000+ retailers who count on Repricer.com to grow their business and manage their pricing."); Tannistho, *AI in Retail: Of Chatbots, Conversations and Dynamic Pricing*, MEDIUM (Nov. 29, 2016), https://medium.com/@tannistho/ai-in-retail-of-chatbots-conversations-and-dynamic-pricing-bf418ae3096c [https://perma.cc/B5WR-KDK5] (describing the 5Analytics AI platform, "where shops can integrate dynamic pricing into their existing systems via standard interfaces").

78. REPRICER.COM, https://www.repricer.com/ [https://perma.cc/788A-KWB8] (last visited July 17, 2022).

79. *Revenue Growth Management (RGM)*, ANTUIT.AI, https://www.antuit.ai/solutions/consumer-goods-cpg/revenue-growth-management [https://perma.cc/FT7Z-L84P] (last visited July 17, 2022).

perception of individual merchants.[80] If sellers can identify these key-value-items and price them appropriately, they can modify consumers' overall view of their market competitiveness.[81] A "competitive-response module" focuses on varying prices in response to real-time changes in rivals' prices,[82] while an "elasticity module" calculates the effects of prices on demand, taking into account seasonality and other factors.[83] Firms also might employ an "omnichannel module," which coordinates pricing strategy among a merchant's various distribution outlets, including between online and brick-and-mortar sales channels.[84]

A significant part of the business of these third-party algorithm vendors is helping companies win sales on the Amazon Marketplace. The Marketplace is Amazon's e-commerce platform, where independent merchants can compete against Amazon's own offerings to make sales to end users.[85] Third-party sellers pay Amazon various fees to join the platform and to gain access to Amazon's enormous customer base.[86] Amazon offers these independent merchants a service called Selling Partner API (SP-API) (formerly Amazon Marketplace Web Service (MWS)), which allows them to interface with Amazon and automate their selling activities, including managing their listings, orders, and payments.[87] SP-API and MWS also provide merchants with market price updates for their products.[88] Third-

80. *See, e.g.*, Dilmegani, *supra* note 71 (providing overview of dynamic pricing and describing key-value-items module); Mathias Kullmann & Stephan Zimmermann, *Dynamic Pricing in E-Commerce*, MCKINSEY & CO., https://www.mckinsey.com/business-functions/marketing-and-sales/how-we-help-clients/dynamic-pricing [https://perma.cc/8A6X-PKCC] (last visited July 17, 2022) (introducing McKinsey's dynamic-pricing services and describing key-value-item module).

81. *See* Dilmegani, *supra* note 71; Kullmann & Zimmermann, *supra* note 80.

82. *See* Dilmegani, *supra* note 71; Kullmann & Zimmermann, *supra* note 80.

83. *See* Dilmegani, *supra* note 71; Kullmann & Zimmermann, *supra* note 80.

84. *See* Dilmegani, *supra* note 71; Kullmann & Zimmermann, *supra* note 80. Other standard modules include a "long-tail" module, which assists companies focused on selling limited volumes of hard-to-find items, and a "time-based pricing module," which adjusts pricing based on the time of day items are bought, time of desired delivery, and product expiration dates. *See* Dilmegani, *supra* note 71; Kullmann & Zimmermann, *supra* note 80.

85. *See* Chen et al., *supra* note 15, at 1340 (describing the Amazon Marketplace).

86. *See id.* (describing the various fees third-party sellers are required to pay Amazon to do business on the Amazon Marketplace).

87. Azsyzg, *Amazon MWS to Selling Partner API Migration Guide*, AMAZON SELLING PARTNER API - SPAPI.CYOU (Dec. 15, 2021, 12:55 AM), https://spapi.cyou/en/guides/selling-partner-api-migration-guide.html#contents [https://perma.cc/9FD6-MTRF] ("The Selling Partner API . . . helps Amazon selling partners programmatically access their data on listings, orders, payments, reports, and more.").

88. *See Pricing Health*, AMAZON SELLER CENT., https://sellercentral.amazon.com/gp/help/external/STH6YN3BR8XNWBW [https://perma.cc/F26W-CM3V] (last visited July 17, 2022) ("The Competitive Price, Featured Offer price, and suggested lower price are published through our MWS APIs."); *Amazon Selling Partner API*, ESELLERHUB, https://www.esellerhub.com/amazon-sp-api-development.html [https://perma.cc/374J-RRE3] (last visited July 17, 2022) (describing how SP-API can be "used to get prices related to the product that is listed on respective marketplace").

party pricing algorithms connect to Amazon's APIs, enabling merchants to automatically adjust their prices on the Marketplace.[89]

Algorithmic pricing appears to be having a significant impact on the Amazon Marketplace. A 2016 study by Le Chen, Alan Mislove, and Christo Wilson applied a methodology for detecting algorithmic pricing on the Marketplace.[90] Using data from four months of sales of more than 1,600 best-selling products, the study identified more than 500 sellers employing algorithmic pricing on the platform.[91] The authors found that merchants using pricing algorithms generally outperformed rivals that did not use this technology.[92] These merchants received more customer feedback, which the authors concluded meant that they had higher sales volumes, and they "won" the Amazon Buy Box more frequently than their competitors, even when they did not offer the best price for a specific product.[93] Winning the Buy Box is crucial, because over eighty percent of Amazon sales are made via the Buy Box.[94] This study and other similar analyses show that Amazon consumers likely are subject to algorithmic pricing for a growing portion of their purchases.

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With its deep penetration into e-commerce (Amazon and many other retailers), transportation services (Uber, airlines), and hospitality (hotels), algorithmic pricing now touches the lives of most consumers. And its reach is only going to spread, through expanded deployment in e-commerce but also in physical retail, where the use of digital labelling technology will allow brick-and-mortar merchants to change prices on the fly.[95]

89. *See* Chen et al., *supra* note 15, at 1341 (Algorithmic pricing "services enable any merchant to easily become a 3P seller and leverage sophisticated dynamic pricing strategies.").

90. *Id.* at 1339.

91. *Id.*

92. *Id.* at 1340.

93. *Id.* The Amazon "Buy Box" is the white box on the right side of each Amazon product page. *Id.* The Buy Box includes a button that allows customers to purchase the product listed in the Box. *Id.* When multiple sellers offer a product, they compete to be featured in the Buy Box. *Id.* at 1341.

94. *Id.*; *see also* Eyal Lanxner, *The Amazon Buy Box: How It Works for Sellers, and Why It's So Important*, BIGCOMMERCE, https://www.bigcommerce.com/blog/win-amazon-buy-box/ [https://perma.cc/T73H-FU5J] ("82% of Amazon sales go through the Buy Box, and the percentage is even higher for mobile purchases.").

95. *See, e.g.*, Zhou, *supra* note 37 (noting that a German supermarket group already has adopted digital labeling technology, which allows it to make "instantaneous price changes to hundreds of different products in thousands of stores").

B. Algorithms and Antitrust: Current Approaches

The explosion in the use of pricing algorithms over the past decade has sparked concerns about their effects on competition and consumers. Accordingly, a growing body of scholarship has analyzed algorithms' potential impact on pricing and competitive conditions. This literature has focused predominantly on two issues: (1) whether pricing algorithms can be used to facilitate express collusion among competing firms, and (2) the conditions under which the use of pricing algorithms might result in tacit collusion among rivals.

On the first issue, a scholarly consensus has emerged that pricing algorithms can facilitate price-fixing and other forms of express collusion.[96] In their influential article on the competitive impact of pricing algorithms, Ariel Ezrachi and Maurice Stucke identified two scenarios in which firms can maintain a price-fixing conspiracy using pricing algorithms.[97] The first, which they term the "messenger" model, is the simplest: human agents at rival firms agree to fix prices and to do so through the use of computers.[98] This is more than merely a theoretical issue: In 2015, the Department of Justice's Antitrust Division prosecuted participants in just such a scheme. The Division alleged that rival sellers of posters entered a conspiracy to fix prices by using "commercially available algorithm-based pricing software to set . . . prices" on the Amazon Marketplace.[99] An individual defendant pled guilty to "agree[ing] to adopt specific pricing algorithms" for selling the posters, "with the goal of coordinating changes to" the conspirators' "respective prices."[100]

The second algorithmic price-fixing strategy Ezrachi and Stucke identified is the "Hub and Spoke," which involves rival sellers' use of a common pricing algorithm to coordinate prices among them.[101] The distinction between this model and the more straightforward "messenger" model is that the rival firms do not agree among themselves to fix prices; instead, they each enter vertical agreements to work with a third-party algorithm, which sets the price.[102] If there is evidence that the common

96. *See, e.g.*, Ezrachi & Stucke, *supra* note 2, at 1784–89 (describing scenarios where firms could use pricing algorithms to explicitly collude); Harrington, *supra* note 7, at 346 ("[P]ricing algorithms . . . are rich enough to encompass the collusive strategies that have been used by human agents.").

97. Ezrachi & Stucke, *supra* note 2, at 1784.

98. *Id.* at 1784–87.

99. Indictment at 2, United States v. Aston & Trod Ltd., No. CR 15-00419 WHO (N.D. Cal. Aug. 27, 2015).

100. Plea Agreement at 4, United States v. Topkins, No. CR 15-00201 WHO (N.D. Cal. Apr. 30, 2015).

101. Ezrachi & Stucke, *supra* note 2, at 1787–89 ("Here, competitors use the same (or a single) algorithm to determine the market price or react to market changes.").

102. *Id.*

algorithm is being used as a tool for fixing prices or otherwise facilitating collusion, the elements of a hub-and-spoke conspiracy might be satisfied.[103]

When algorithms are used to maintain an explicit price-fixing conspiracy, the legal intervention is clear: prosecution under section 1 of the Sherman Act.[104] The involvement of an algorithm may change the nature of the available evidence, but the legal analysis is not novel, especially in cases where human agents from rival firms agree to employ an algorithm to fix prices.

The second question posed above—can the use of pricing algorithms facilitate tacit collusion?—raises more difficult problems of proof and remedies. Tacit collusion, or conscious parallelism as it is sometimes called, occurs when rival firms set prices at a supracompetitive level *without* forming a cartel or other explicit arrangement to do so.[105] Instead, firms form a shared understanding with no direct communication, potentially through subtle and lawful signals. For example, one firm may unilaterally raise its price to the collusive price to see if its rivals follow. When all firms share a mutual understanding of a target price and that rivals will respond to any price cut with an extended period of even lower prices, firms can charge consumers higher prices than they would in a competitive market. As in explicit collusion, firms have a short-term incentive to reduce their prices, but they are deterred from doing so because of the threat of future punishment, in the form of lower prices and lower profits.

Not all markets are susceptible to tacit collusion; for conscious parallelism to take place, markets typically must exhibit certain characteristics. Some combination of transparent pricing, homogeneous products, high entry barriers, and market concentration is necessary for firms to be able to maintain prices above a competitive level in the absence of an explicit agreement to do so.[106] Without a high degree of similarity among products and long-standing relationships among competitors, it is

103. *Id.* at 1788.

104. *See* Roger Alford, Deputy Assistant Att'y Gen., Antirust Div., U.S. Dep't of Just., Address at King's College: The Role of Antitrust in Promoting Innovation (Feb. 23, 2018) ("Where firms agree to set their pricing algorithms to coordinate on price, this is a traditional Section 1 violation.").

105. *See, e.g.*, Brooke Grp. Ltd. v. Brown & Williamson Tobacco Corp., 509 U.S. 209, 227 (1993) ("Tacit collusion, sometimes called oligopolistic price coordination or conscious parallelism, describes the process, not in itself unlawful, by which firms in a concentrated market might in effect share monopoly power, setting their prices at a profit-maximizing, supracompetitive level by recognizing their shared economic interests and their interdependence with respect to price and output decisions.").

106. *See, e.g.*, Deng, *supra* note 13, at 92 ("[T]he structural characteristics that tend to facilitate/disrupt collusion" include: "Symmetric competitors. Fewer competitors. More homogeneous products. Higher barrier to entry. More market transparency. More stable demand. Small and frequent purchases by customers."); *In re* Text Messaging Antitrust Litig., 782 F.3d 867, 871 (7th Cir. 2015) ("[T]he fewer the firms" in a relevant market "the easier it is for them to engage in 'follow the leader' pricing ('conscious parallelism,' as lawyers call it, 'tacit collusion,' as economists prefer to call it) . . . .").

difficult for firms to fully understand the motives underlying the pricing behaviors of rivals. This makes it challenging for firms to arrive at a tacit arrangement about the optimal pricing strategy. Entry barriers deter new firms from entering the market and disrupting the cartel.

Some scholars have argued that pricing algorithms can facilitate tacit collusion.[107] One way they might do so is through the speed at which they can discover and react to changes in rivals' pricing. Once competing firms realize that algorithms will quickly detect any price reduction and react by cutting prices even further, they are less likely to deviate from the supracompetitive collusive price.[108] Or, pricing algorithms might facilitate tacit collusion because their use requires increased pricing transparency and they set prices in a predictable manner, reducing uncertainty.[109] The increasing sophistication of pricing algorithms makes it easier to figure out how to coordinate pricing successfully and to do so more quickly.[110]

Other scholarship, particularly in the computer science and experimental economics literature, disputes the extent to which algorithmic tacit collusion is a threat at present.[111] This body of work asserts that, absent explicit instructions from human agents, it is difficult for algorithms in markets with more than two competitors to tacitly collude. Ulrich Schwalbe describes the likelihood of algorithmic collusion currently as "belong[ing] to the realm of legal sci-fi."[112]

To the extent pricing algorithms increase the threat of tacit collusion, finding an appropriate intervention is challenging. Courts have interpreted section 1 of the Sherman Act, which addresses collusion, to require an

107. *See. e.g.*, Deng, *supra* note 13, at 88 ("[T]here is growing experimental evidence that an algorithm can be designed to tacitly collude."); Gal, *supra* note 6, at 69 ("Coordination-facilitating algorithms are already available off the shelf, and such coordination is only likely to become more commonplace in the near future."); Mehra, *supra* note 2, at 1373 ("[T]acit collusion becomes more likely with robo-sellers . . . .").

108. *See* Ezrachi & Stucke, *supra* note 2, at 1789 (Pricing algorithms can reach "a similar common understanding that is not explicitly negotiated but comes about with the computer learning to quickly detect and punish rivals' price cutting.").

109. *Id.* at 1790 ("By shifting pricing decisions to computer algorithms, competitors increase transparency, reduce strategic uncertainty . . . and thereby stabilize the market.").

110. *See* Gal, *supra* note 6, at 82.

111. *See, e.g.*, Ulrich Schwalbe, *Algorithms, Machine Learning, and Collusion*, 14 J. COMPETITION L. & ECON. 568, 570 (2018) ("Given the current state of research in artificial intelligence (AI) and machine learning, concerns about the collusion of algorithms do not currently seem justified."); Thibault Schrepel, *The Fundamental Unimportance of Algorithmic Collusion for Antitrust Law*, JOLT DIG. (Feb. 7, 2020), https://jolt.law.harvard.edu/digest/the-fundamental-unimportance-of-algorithmic-collusion-for-antitrust-law [https://perma.cc/9FVQ-YBCS] ("Algorithmic collusion is the subject of a growing literature, yet, empirical studies documenting the frequency of the phenomenon in the real-world remain to be produced.").

112. Schwalbe, *supra* note 111, at 600.

explicit agreement among firms for liability to attach.[113] Conscious parallelism therefore is lawful even though it causes consumers to pay higher prices than they would in a competitive market.[114] Scholars have suggested a number of strategies for addressing algorithm-driven tacit collusion. These include market-based solutions, antitrust, and regulatory interventions. Michal Gal, for example, has proposed that consumers can employ their own algorithms to counter sellers' algorithms.[115] This market-based approach would empower consumers to fight back by using algorithms to identify coordinated pricing so they can avoid those sellers and to potentially create buyer power for negotiating leverage.[116] Gal cautioned that these potential solutions have significant limitations, however, including presenting their own antitrust risks if buyers use their algorithms to enter anticompetitive agreements.[117] She concluded that market-based approaches to countering pricing algorithms are, "at best, partial" cures and are not "a panacea."[118]

Legal interventions also present challenges. Proposed responses fall into two main buckets: antitrust solutions—which typically would require a reinterpretation or expansion of current case law—and regulatory solutions. On the antitrust front, scholars have suggested a range of fixes, including expanding the definition of "agreement" for purposes of section 1, broadening antitrust law to bar tacit collusion altogether, and treating the use of algorithms as an unlawful "facilitating practice" that makes achieving collusion easier.[119] Gal, for instance, contends that the section 1 agreement

113. *See In re* Text Messaging Antitrust Litig., 782 F.3d 867, 879 (7th Cir. 2015) ("Tacit collusion . . . does not violate section 1 of the Sherman Act. Collusion is illegal only when based on agreement.").

114. *Id.* at 874–75 (observing that competing firms raising prices absent a conspiracy to do so is "merely tacit collusion, which to repeat is not illegal").

115. *See* Gal, *supra* note 6, at 94–97 (describing several ways consumers can use algorithms to counteract algorithmic collusion); Michal Gal, *Limiting Algorithmic Cartels*, 38 BERKELEY TECH. L. J. 22–25 (forthcoming 2023), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4063081 [https://perma.cc/XG6T-K6U6] (arguing that "algorithmic consumers have the potential to break down algorithmic coordination").

116. Gal, supra note 6 at 95.

117. *Id.* at 96.

118. *Id.* at 96–97.

119. *See* Ezrachi & Stucke, *supra* note 17, at 242 ("The FTC can attempt to reach the industry-wide use [of] algorithms as a facilitating practice."); Gal, *supra* note 6, at 110–15 (analyzing algorithms as facilitating practices); *id.* at 99 ("[S]ome prominent scholars suggest that the term 'agreement' is sufficiently broad to capture conscious parallelism."); *id.* at 117 (arguing that in light of the increasing threat of algorithmic collusion, "the time may be ripe to reconsider prohibiting any conduct with potential anticompetitive tendencies with no offsetting pro-competitive ones, even where such conduct does not constitute an agreement in the traditional sense"); *see also* ORG. FOR ECON. COOP. & DEV., *supra* note 11, at 36 (raising "the concern of whether the need to address algorithmic collusion should require a new definition of what is an agreement for antitrust purposes," and noting that "[t]his is not a new question for antitrust scholars but the question has come up again in recent times.").

requirement should be satisfied—even where human agents from rival firms have not entered an agreement—if a programmer intended an algorithm to reach a collusive pricing outcome.[120]

If an antitrust solution is unavailable to address the increased risk of algorithmic tacit collusion, then regulation may be necessary to protect consumers. Scholars have proposed various regulatory interventions to counter the threat that algorithms pose to competitive pricing, including requiring firms to disclose the details of their algorithms and their data inputs; barring algorithms from using certain types of data inputs (e.g., rivals' prices); and imposing time lags on pricing adjustments so that a maverick firm could profitably lower its prices without its rivals immediately matching those price cuts.[121] Another potential solution is direct price regulation in markets where algorithms have facilitated tacit collusion. Ezrachi and Stucke suggest that "Big Data" and "Big Analytics" might allow governments to effectively set prices using their own algorithms, though they note various risks with this approach, including distorting industry incentives and regulatory capture.[122] Further, as pricing algorithms become more common and are adopted in more markets, price regulation would become an enormous regulatory undertaking that likely would alter the nature of government and its relationship to the economy and the citizenry.[123]

The existing competition literature on pricing algorithms focuses on the potential for collusive outcomes, be they explicit or tacit. These studies presume immediate or eventual cooperation among algorithms, leading to higher prices. They also presume that the algorithms firms employ are essentially equivalent in quality and in their ability to collude.[124] There will be markets, however—perhaps many markets—where firms employ competing algorithms of differing quality. Take a market with three firms, 1, 2, and 3. Firm 3 may use a highly sophisticated algorithm that is able to set prices many times a day in response to changes in market conditions,

120. *See* Gal, *supra* note 6, at 107–11; *see also* Ezrachi & Stucke, *supra* note 2, at 1789–91 (referring to this possibility as the "predictable agent" scenario).

121. *See* Ezrachi & Stucke, *supra* note 2, at 1799–1805; *see also* Gal, *Limiting Algorithmic Cartels*, *supra* note 115 at 33–36 (proposing that when a supra-competitive equilibrium is identified one competitor's price should be frozen so that its rivals can lower their prices and capture the price-frozen firm's customers); ORG. FOR ECON. COOP. & DEV., *supra* note 11, at 50 ("If the purpose is to prevent companies from independently coordinating anti-competitive prices, regulations could inhibit algorithms from reacting on particular features or market variables that are necessary to sustain tacit coordination," including "program[ming algorithms] not to react to most recent changes in prices.").

122. Ezrachi & Stucke, *supra* note 2, at 1807.

123. *See, e.g.*, *id.* ("[T]he road to perfect price regulation may also lead to a world of limited privacy, among other things.").

124. See, e.g., Calvano et al., *supra* note 37, who assume symmetric firms with identical technology, as is standard in the existing algorithmic collusion literature.

while Firm 2 relies on a less sophisticated algorithm that can set prices only once a day, and Firm 1 employs an algorithm that can set prices just once a week. Despite the likely prevalence of this type of market, there have been no legal analyses to date of scenarios where, instead of colluding, algorithms compete. To address this gap in the literature, the next Part describes a game-theoretical model of algorithmic competition developed by Zach Brown and Alexander MacKay and demonstrates how this model differs from standard approaches to oligopoly theory. This analysis shows that competition among pricing algorithms results in higher prices for consumers even absent collusion.

II. PRICING ALGORITHMS & COMPETITION: ECONOMIC THEORY

Economic analyses of the types of competitive scenarios involving pricing algorithms that concern antitrust scholars are grounded in oligopoly theory. This robust body of theoretical literature has its origins in the nineteenth-century work of Antoine Cournot and Joseph Bertrand, and it extends to contemporary game theoretical analysis pioneered by John Nash. To understand how pricing algorithms might affect firm behavior, this Part begins by surveying classic oligopoly models. It then discusses how pricing algorithms can change the outcomes these classic models might predict by allowing firms to shift between modes of competition. This analysis shows that algorithmic pricing will result in supracompetitive prices even in the absence of collusion. Emerging empirical evidence supports this conclusion.

A. Classic Oligopoly Models

While economists have developed many sophisticated models to explain the competitive interactions of firms, three key contributions dominate this theoretical landscape: the Cournot model, the Bertrand model, and the Nash non-cooperative equilibrium.

The Cournot model, introduced in 1838, posits a market for a single, undifferentiated (homogeneous) product in which a set of firms compete by choosing the quantity of that product to produce.[125] The Bertrand model, from 1883, is often applied to markets featuring differentiated (non-homogeneous) products, and it assumes that firms compete by choosing prices, not quantities.[126] In modern oligopoly theory, the Cournot and

125. *See* Gregory J. Werden, *Economic Evidence on the Existence of Collusion: Reconciling Antitrust Law with Oligopoly Theory*, 71 ANTITRUST L.J. 719, 722 (2004).

126. *Id.* at 723.

Bertrand models are interpreted in light of the Nash equilibrium theory, pioneered in 1950.[127] Using game theory to describe the interactions of competing firms, Nash posited that an equilibrium[128] outcome in a non-cooperative game[129] will occur when each player, knowing the strategies of the other players, has no incentive to change their current strategy. So, if three firms compete in a market and each, by observing the market, understands its rivals' strategies, and all three determine that they cannot gain a competitive advantage by unilaterally changing their own strategy, the market has achieved a Nash non-cooperative equilibrium. Another way to think about the Nash equilibrium is that it describes a "self-enforcing agreement" among firms.[130] Without explicitly agreeing on any specific course of action, the firms in a Nash equilibrium have reached a state where none of them will unilaterally change their current strategy.

Modern economic theory uses the Nash non-cooperative equilibria of the Bertrand and Cournot models to determine competitive price levels. The Cournot-Nash equilibrium describes a model in which, based on their knowledge of the *quantities* their rivals produce, each firm is satisfied with the quantity it chooses to produce and will not unilaterally alter its competitive strategy.[131] The Bertrand-Nash equilibrium describes a model in which, based on their knowledge of their rivals' *prices*, each firm is satisfied with the price it chooses to charge and will not unilaterally change its competitive strategy.[132]

While these two equilibria may appear similar in some respects, their outcomes can be significantly different. Both models predict lower prices and higher output as the number of competitors in a market increases.[133] When applied to differentiated products, the Bertrand-Nash equilibrium price depends on how differentiated the products are.[134] If they are imperfect substitutes, each firm will charge a markup, and equilibrium prices will be above marginal costs. The closer the products are to being perfect substitutes, the lower the markup and the resulting equilibrium price.[135] With homogeneous products, which are perfect substitutes, the Bertrand-

127. *Id.* at 721–24.

128. An equilibrium is a set of strategies chosen by all players such that no player has an incentive to alter its strategy. *See id.* at 721.

129. In a Nash non-cooperative game, each player chooses strategies independently of the other players, taking as given the strategies chosen by the other players. *See id.*

130. *See* Dennis W. Carlton, Robert H. Gertner & Andrew M. Rosenfield, *Communication Among Competitors: Game Theory and Antitrust*, 5 GEO. MASON L. REV. 423, 430 (1997).

131. *See* Werden, *supra* note 125, at 722.

132. *Id.* at 723.

133. *Id.* at 722–23.

134. *Id* at 723.

135. *Id.*

Nash equilibrium generates prices that are equal to marginal costs, even when only two firms are in the market.[136]

The Cournot model is also applied to markets with homogenous products. However, unlike the Bertrand-Nash equilibrium, the Cournot-Nash equilibrium price in an oligopoly market is above marginal costs, so that all firms earn positive markups.[137] Thus, despite facing identical demand conditions, the mode of competition—i.e., whether firms compete à la Bertrand or à la Cournot—has substantial implications for price levels.

The Cournot and Bertrand models therefore present an interesting case where different models of firm behavior deliver different market outcomes, even when other market conditions are identical. Moreover, the Nash equilibria under both models are considered *competitive* equilibria because each firm is acting non-cooperatively to pursue its own self-interest. This provides a useful illustration of a key mechanism in our paper: the choice of the mode of competition (in prices or in quantities) can affect equilibrium prices.[138] If firms in homogeneous product markets could choose between the two, they would opt for the Cournot model that yields higher prices.

One challenge in applying these theories to antitrust analysis is deciding which model to employ in a given market. Both models are actively used in empirical work. Researchers and antitrust authorities have almost exclusively applied the Cournot model to industries with homogeneous products, likely because firms usually earn some markup over marginal costs in real-world settings.[139]

Another challenge is determining what happens when firms have repeated interactions in the same market over time. Much of modern oligopoly theory focuses on this second challenge, and in particular on whether collusion can be sustained when firms choose quantities or prices in such settings. The Cournot and Bertrand models discussed above are "one-shot games" in which firms have one opportunity to make their quantity or pricing decisions. In most real-world markets, firms are continually making quantity and pricing decisions. "Repeated games,"

136. *Id.* at 723–24.

137. *See id.*

138. *See id.* ("As a general matter, changing the rules of the game (e.g., from having players choose prices to having them choose quantities) can substantially affect the outcome.").

139. The Cournot model can alternatively be justified as a two-stage game where firms first choose production capacities, and then compete in prices after pre-committing to capacities. *See* David M. Kreps & José A. Scheinkman, *Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes*, 14 BELL J. ECON. 326, 326–27 (1983). Thus, the Cournot model has been applied to industries such as cement and electricity, where products are homogenous and capacities are observable. *See, e.g.,* Stephen P. Ryan, *The Costs of Environmental Regulation in a Concentrated Industry*, 80 ECONOMETRICA 1019 (2012); Meredith L. Fowlie, *Incomplete Environmental Regulation, Imperfect Competition, and Emissions Leakage*, 1 AM. ECON. J.: ECON. POL'Y 72 (2009).

which comprise multiple "stage games," are intended to capture this reality. In these games, firms play the Cournot or Bertrand game multiple times with the same rivals. Under these circumstances, firms in a concentrated market can move from the competitive equilibrium of a one-shot game toward a collusive equilibrium, in which firms—recognizing their mutual interests and employing strategies to discipline price-cutters—will raise prices above the competitive level.[140] In other words, given repeated interactions over time, firms in concentrated markets can coordinate on supracompetitive prices even without an explicit agreement to do so. These tacitly collusive outcomes are more fragile than the competitive equilibria because every firm has a short-run incentive to steal market share from their rivals, either by cutting prices or increasing output. Explicit collusion also faces the same pressures to deviate, even though all rivals have agreed to the strategies that will be played. An analysis of whether or not collusion is likely in a market is guided by a set of factors that render cooperation favorable.[141]

The theoretical landscape therefore features three models of firm interaction: a competitive outcome (one-shot games), a coordinated outcome absent explicit agreement (repeated games), and explicit collusion where an agreement governs firm interaction. To date, scholars working in this landscape share the assumption that firms cannot alter the model of competition in a specific market. If market characteristics suggest that firms compete by choosing quantities (Cournot model), current scholarship (implicitly) assumes that firms will not switch to a model in which they choose prices instead (Bertrand model). The development of pricing algorithms undermines this key assumption by allowing firms to change the model of competition in a market.

B. Pricing Algorithms Change the Competitive Game

Pricing algorithms add a new element to the theoretical analysis of price competition. When firms use pricing algorithms, it is no longer accurate to represent a firm's strategic decision in terms of prices, as is done in the Bertrand model. Firms' strategies consist of algorithms that determine prices. Thus, instead of choosing prices directly, each firm chooses an algorithm to effectively act as a "representative" for the firm. The algorithm then sets prices according to a specific set of rules, which are determined by

140. This is often discussed in terms of the "Folk Theorem." *See, e.g.*, Werden, *supra* note 125, at 729–31.

141. *See, e.g.*, U.S. DEP'T. OF JUST., *supra* note 42, at 5–6 (listing industry conditions "favorable to collusion"). Such factors include a small number of sellers, products lacking easy substitutes, homogeneous products, repetitive purchases, and rivals who "know each other well." *Id.*

the firm. By choosing the rules instead of the prices, firms can effectively select among different modes of competition, akin to allowing firms to switch from Bertrand to Cournot. Brown and MacKay show that pricing algorithms provide firms with two mechanisms for changing the competitive game: they allow firms to vary the *frequency* with which they price and to signal *commitment* to a pricing strategy.[142] In equilibrium, these mechanisms can produce different competitive outcomes than the Cournot or Bertrand models would predict. In other words, algorithms enable firms to choose how they compete with rivals, affecting the incentives of all firms in the market and the profits they can earn. We consider the impacts of one or more firms adopting pricing algorithm technology relative to a hypothetical starting point where all firms compete on prices.

These effects can be captured by three scenarios. First, imagine a scenario where a pricing algorithm allows one firm to update its prices more frequently than its rival. For example, one firm may have technology that allows it to update prices multiple times per day, whereas the other firm can update prices only once per week. Brown and MacKay describe this situation as a market with "asymmetric frequency."[143] Second, consider a scenario where one firm has encoded its pricing strategy into an algorithm, and this algorithm determines price changes at a high frequency without human intervention. If the algorithm has the ability to monitor and react to the price changes of its rival, this market features "asymmetric commitment."[144] Finally, the third scenario is one in which both firms have high-frequency algorithms that adjust prices without human intervention, and both algorithms react autonomously to the price changes of rivals. Brown and MacKay term this situation "symmetric commitment."[145]

Brown and MacKay's analysis shows that both asymmetric frequency and asymmetric commitment can result in prices above the competitive level for each firm.[146] It also demonstrates that symmetric commitment can generate higher prices, including prices equivalent to fully collusive prices, even when algorithms are prohibited from employing collusive strategies. Indeed, when each firm's algorithm depends on the prices of rivals, in equilibrium, prices will *never* be at the competitive (Bertrand) level.[147] Considered together, these models demonstrate that algorithms will

142. *See* Brown & MacKay, *supra* note 14, at 7.
143. *Id.* at 18.
144. *Id.* at 22–24.
145. *Id.* at 27.
146. *Id.* at 22–24.
147. *Id.* at 29–30.

fundamentally change the pricing landscape by allowing firms to charge supracompetitive prices even in the absence of collusion.

1. Frequency

To understand the impact of algorithms on pricing frequency, consider a simple scenario with two firms. Firm 1 has technology that enables it to update its price once per week. Initially, its rival, Firm 2, has the same technology and also sets its price at the same time each week. Assume that each firm has a single product, that these products are imperfect substitutes, and that the firms are symmetric in terms of demand conditions and costs. This scenario approximates the historical pricing patterns for brick-and-mortar grocery and drug stores. In this setting, the competitive Bertrand-Nash equilibrium is one in which each firm charges the same price. Firms earn a markup over marginal costs because the products are differentiated.

Next, consider what happens when one firm introduces pricing technology that allows it to set prices at a higher frequency. In this revised scenario, assume Firm 1 continues to set prices only at the beginning of the week, but Firm 2 adopts new pricing technology that allows it to update its prices once each day during the week. The firms now price at an asymmetric frequency, and this is known by both firms.

Brown and MacKay show that under these circumstances the competitive outcome will be different than the Bertrand-Nash equilibrium.[148] Firm 1 will determine its price for the entire week with the knowledge that Firm 2 can change its price the next day. In typical cases, it is optimal for Firm 2 to undercut any price chosen by Firm 1 that is above the Bertrand-Nash level.[149] Because Firm 2 can change its price in response to Firm 1's price, Firm 2 can now effectively "threaten" Firm 1 with deeper price cuts. As a result, the Bertrand logic where Firm 1 considers price changes assuming Firm 2's price is fixed no longer applies. Firm 1 instead will choose a price that will maximize its profit in light of Firm 2's anticipated response the following day.[150]

Knowing that Firm 2 will undercut its price, Firm 1 will set a price above the competitive level.[151] Firm 2 will choose its price (each day) to maximize its own profits. This price will be below Firm 1's price but above the competitive level. Because the products are differentiated, Firm 1 will

148. *Id.* at 22.

149. *Id.* at 25. Brown and MacKay focus on the case where prices are strategic complements, which is the usual case for differentiated products. *See* JEAN TIROLE, THE THEORY OF INDUSTRIAL ORGANIZATION 337, 364 (1988).

150. Brown & MacKay, *supra* note 14, at 20–22.

151. *Id.* at 21–22.

continue to attract some customers, despite its higher price. In this scenario, both firms can obtain higher profits than they would in the Bertrand-Nash equilibrium.[152] Firm 2's adoption of a superior pricing technology creates an asymmetry in pricing frequency that allows the firms to commit to a leader-follower pricing pattern, resulting in higher prices for consumers.[153]

Even though Firm 1 is disadvantaged relative to Firm 2, Firm 1 earns higher profits than in the scenario where both firms have the same pricing frequency. If Firm 1 were to adopt daily pricing frequency to match Firm 2's technology, prices would revert to the Bertrand-Nash level. The difference in pricing frequency is what permits firms to maintain a leader-follower order and charge higher prices. Thus, in markets where firms employ pricing algorithms, there are potentially strong profit incentives leading firms to choose different pricing frequencies. Firms do not need to coordinate or collude on this arrangement, as it is in their unilateral best interests. This means that in markets where firms sustain symmetric pricing, other factors likely are at work. For example, in some markets, it may be technologically challenging or prohibitively expensive to adopt technology that allows for more frequent price changes.[154] Or less frequent price variations might be too costly, because they may prohibit a firm from adjusting to changes in demand and supply. To enhance the ability to adjust to changing conditions, in some circumstances we may see all firms in a market adopting higher-frequency pricing technology, even if it results in symmetric pricing frequency.[155]

In our example, we have discussed a case with two firms, but the same logic applies to an oligopoly setting with several firms and a wide range of choices for pricing frequency. The firms with slower price changes will internalize the subsequent reactions of faster firms, causing them to increase prices above Bertrand-Nash levels.

While these firms will react to each other's prices in a way that leads to supracompetitive pricing, the outcome is different from that of collusion. In the example above, colluding firms would charge the same price. At that price, each firm would want to undercut its rival, stealing market share and increasing profits. In the scenario we describe, the firms are competing on price, and the prices differ, with superior-technology firms charging lower prices. Further, collusion is maintained by a reward-punishment scheme where firms are rewarded when they maintain a supracompetitive price and

152. *Id.*
153. *Id.* at 22.
154. *Id.* at 26–27.
155. *Id.*

punished when they deviate from it.[156] That is not the strategy we describe here. By introducing differences in pricing frequency, algorithms enable all firms to price above the competitive level in a non-cooperative equilibrium.

2. Commitment

The second feature of pricing algorithms that can change the competitive game is commitment. In the discussion of pricing frequency above, the assumption is that firms have the flexibility to choose any price whenever they update prices. In practice, algorithms often have less flexibility and are restricted by a set of rules that are encoded in software.[157] These rules may be quite complicated, and they may evolve over time. Regardless, the chosen price can be traced directly to underlying code. Thus, algorithms provide firms with the ability to commit to a set of (inflexible) rules when determining prices. Importantly, these rules often depend on the prices of rivals.

If firms choose algorithms optimally, how would the encoded pricing rules reflect rivals' prices? Brown and MacKay address this question by considering two different scenarios, one in which only one firm has the ability to make such a commitment and a second in which both firms have this ability.

In the first scenario, "asymmetric commitment," one firm has an algorithm that allows for an automated response to the price changes of its rival. As before, consider Firm 1 to have the inferior technology. Each firm can set their algorithms once at the beginning of the week. Over the course of the week, these algorithms may adjust prices due to changing demand conditions or inventories, but only Firm 2 can adjust to changes in its rival's prices. For example, suppose that Firm 2's algorithm scrapes Firm 1's price once per day and uses the observed price to update its own price. In this way, Firm 2's algorithm commits it to react to price changes by Firm 1. This is a realistic scenario: many markets feature competitors with varying abilities to monitor and react to rivals' pricing.[158]

In this setting, Firm 1 will determine its algorithm in a way that will maximize its own profits, taking into account Firm 2's algorithmic response.[159] What pricing rule will Firm 2 use to react to the price of Firm 1? Brown and MacKay show that it is optimal for Firm 2 to encode in its

156. *See, e.g.*, Harrington, *supra* note 7, at 336 ("*Collusion* is when firms use strategies that embody a reward-punishment scheme which rewards a firm for abiding by the supracompetitive price and punishes it for departing from it.").

157. *See* Brown & MacKay, *supra* note 14, at 7.

158. *See, e.g.*, *infra* Section II.C. (discussing empirical evidence of variations in pricing technologies in the online market for over-the-counter allergy drugs).

159. *See* Brown & MacKay, *supra* note 14, at 25.

algorithm the exact behavior Firm 2 would want to use if it were flexibly choosing prices each day.[160] Thus, the outcome in the asymmetric commitment setting mirrors the outcome in the case of asymmetric frequency discussed above. Firm 1 ends up with a price above the competitive level and Firm 2 has a price that is lower yet also above the competitive level. Both asymmetric frequency and asymmetric commitment lead to the same equilibrium with supracompetitive prices.[161]

In the second scenario, "symmetric commitment," both firms employ algorithms that autonomously react to changes in rivals' prices. Unlike the asymmetric scenarios described above, these firms have equivalent pricing technology. The hypothetical real-world environment is one in which all firms adopt algorithms that adjust at a very high frequency. Again, a key assumption is that these algorithms can update prices faster than the firms update their algorithms, so that the algorithms provide short-term commitment to their pricing strategies. In determining what pricing rules to employ, each firm considers that rivals also have commitment encoded in their algorithms. Brown and MacKay address this scenario by extending the Nash non-cooperative equilibrium to a game where firms choose pricing algorithms that are functions of rivals' prices.[162]

Thus described, this model is flexible enough to allow algorithms to encode collusive schemes directly. Brown and MacKay use potential enforcement by a competition authority to rule out such cases, under the notion that these "obviously collusive" strategies would be subject to typical price-fixing charges.[163] They then focus on strategies that (1) do not admit multiple solutions and (2) are continuous functions of rivals' prices. Both of these conditions are sufficient to rule out reward-punishment schemes that characterize collusion.[164]

Despite narrowing the focus only to strategies that appear to be competitive, symmetric commitment allows firms to support supracompetitive prices. In fact, Brown and MacKay show that the joint profit-maximizing price levels (i.e., the collusive outcome) can be achieved using only very simple algorithms.[165] Specifically, Brown and MacKay explore linear algorithms of the form $p_2 = a + bp_1$, where the slope, b, specifies how much Firm 2's price changes for every one-cent change by

160. *Id.* Formally, Firm 2 would find it optimal to encode its Bertrand reaction function into its algorithm.

161. *Id.* at 25–26.

162. *Id.* at 27–28.

163. *Id.* at 29.

164. *Id.* at 28–29.

165. *Id.* at 31–32.

Firm 1.[166] For example, the algorithm may follow the heuristic: "reduce my price by $0.50 for every $1 reduction by my rival." Due to the high frequency with which the algorithms are able to react, a rule along these lines may increase prices by as much as an agreement to collude.[167] Because firms do not want their rivals to reduce prices, such a commitment may discourage all firms from cutting prices, thereby maintaining prices at high levels. The slope of the algorithm may be chosen so that rivals would not want to deviate from collusive price levels.

This result raises two key challenges for antitrust enforcement under current law. First, the algorithms do not resemble reward-punishment strategies that characterize collusion. Moreover, the optimal competitive price response may qualitatively appear the same as a strategy that delivers higher prices. For example, in some settings, the optimal competitive reaction is a linear function of rivals' prices, as in the example above.[168] In such settings, the only difference between linear strategies that deliver competitive price levels and those that deliver collusive price levels is different values of a and b. Thus, the distinction is quantitative, rather than qualitative. This poses a detection challenge for competition authorities: it may be possible to observe all firms' algorithms, yet still not know whether the resulting prices are substantially elevated above competitive levels. To make that determination, authorities would have to know the competitive values of a and b. By contrast, competition authorities are able to identify whether a strategy is collusive because of its reward-punishment characteristics. Brown and MacKay provide an important qualitative result in this regard: if both firms' algorithms depend on rivals' prices, then we should not expect competitive price levels in equilibrium.[169] The presence of reciprocal automated price reactions is a flag for supracompetitive price levels.

The second challenge is that firms may arrive at these strategies unilaterally, without any incentive to deviate from the achieved equilibrium. In other words, when using algorithms, behavior that is consistent with a Nash non-cooperative equilibrium can enable firms to reach outcomes that are only possible with cooperation or collusion when firms compete by choosing prices. It is not clear that, legally, the unilateral adoption of such algorithms constitutes any sort of agreement, tacit or explicit. As Brown and MacKay demonstrate, firms can independently arrive at collusive prices

166. *Id.* at 31. For example, suppose $a = 2$ and $b = 0.5$. If Firm 1 sets its price to $4, then Firm 2 would also choose a price of $4. If Firm 1 lowered its price to $3, then Firm 2 would lower its price to $3.50.

167. *See id.* at 32.

168. *See id.*

169. *See id.* at 29–30.

solely through random experiments to test and improve the parameters of their linear algorithms.[170]

The presence of algorithms does not rule out the possibility of collusive equilibria occurring in repeated interactions. Instead, it raises what is perhaps a more troublesome prospect: that algorithms provide firms with an opportunity to increase prices without resorting to collusive behavior. If firms have the option to choose between adopting algorithms or pursuing collusion, they may opt for algorithms that deliver higher prices and profits without the risk of antitrust enforcement.

In this way, pricing algorithms may reduce the likelihood of explicit collusion. The benefit to be gained from colluding versus competing in algorithms is smaller relative to the gain versus competing in prices, precisely because algorithms move firms closer to the joint profit-maximizing outcome.

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The models discussed above support two conclusions about the effects of pricing algorithms. First, when the use of algorithms results in asymmetries in pricing frequency or commitment, prices will be higher than the competitive equilibrium. Second, when firms compete using algorithms that can incorporate rival firms' pricing, very simple algorithms can generate supracompetitive prices, including the collusive price, even in the absence of collusion. In all these scenarios, pricing algorithms function as self-enforcing agreements, as in the Nash non-cooperative equilibrium. While firm interaction leads to higher prices in these models, algorithms provide many more possibilities than the collusive outcome. In cases with asymmetric technology, there may be large differences in prices across firms. It is possible for each firm to charge a different price, though all prices exceed the competitive price. These models allow us to predict that, even in competitive markets, the increasing use of pricing algorithms will result in higher prices for consumers.

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170. *Id.* at 32. The game with symmetric commitment supports many different equilibria. *See id.* at 28. Brown and MacKay argue that higher-price equilibria are likely to result in typical cases, for two key reasons. *See id.* at 4. First, algorithms are likely to adjust prices in the same direction of the price changes of rivals, e.g., a price cut by a rival results in a price decrease for the firm. *See id.* at 32. If the algorithms have this feature, higher prices result. *See id.* In typical settings, it would be counterintuitive for a firm to increase its price in response to a price cut by a rival. *See id.* Second, Brown and MacKay use simulations to show that firms that use experiments to test and improve their algorithms end up with supracompetitive prices near the collusive price. *See id.* This result occurs because many of the possible equilibria are "knife-edge" cases, arising only if the parameters of the algorithms across firms line up in an exact way. *Id.* It is more likely for a firm to realize an increase in profits when choosing parameters that push it toward the collusive price level. *Id.* at 30.

C. Empirical Evidence

While there is substantial evidence on the spread and scope of algorithmic pricing in many markets, especially in e-commerce, few empirical studies have been performed measuring the effects of these technologies on market prices. The Chen, Mislove, and Wilson study discussed above tracked the penetration of algorithmic pricing in the Amazon Marketplace and showed how the technology affects competitiveness among merchants, but it did not attempt to demonstrate whether algorithmic pricing results in higher or lower prices for consumers.[171] Brown and MacKay performed an empirical study addressing this issue.

Brown and MacKay compiled data on the hourly prices five online retailers charged for seven brands of over-the-counter allergy drugs.[172] The data is from the period April 2018 through October 2019 and comprises over 3.5 million price observations.[173] Those data show significant differences among the five retailers in the number of products they reprice each day and the frequency of those price adjustments. Labeling the retailers A through E, the authors found that retailer A repriced around one-third of its products a day and made about two price adjustments per product per day, while retailer C repriced less than 1% of its products per day and made just one price change per day for those products.[174] The study also demonstrated that the pricing technologies the retailers employed varied greatly in quality. Three of the retailers (A, B, and C) changed prices at various times during the week, while the remaining two retailers (D and E) made almost all of their price changes on Sundays.[175] Further, retailers A and B made pricing changes at different times during the day, while retailers C, D, and E made changes only during the morning.[176] Brown and MacKay concluded that retailers A and B employed superior pricing technology that allowed them to change prices at any hour of any day.[177] Retailer C had technology that allowed for price updates at most once per day, while retailers D and E could change prices only on Sunday mornings.[178]

171. *See supra* notes 90–94.
172. *See* Brown & MacKay, *supra* note 14, at 8.
173. *See id.* at 9.
174. *See id.* at 8–9.
175. *See id.* at 10–11.
176. *See id.*
177. *See id.* at 10.
178. *See id.* The authors define pricing technologies in this setting as including not only the algorithm itself and the computers that implement it, but also "managerial or operational constraints" that limit the ability to change prices more frequently. *Id.*

Brown and MacKay also found evidence that the faster firms were more likely to change the price of a particular product after a slower retailer changed the price of that product.[179] The authors concluded that this was an indication that the faster firms' algorithms were monitoring and responding to the slower firms' prices, which is consistent with their theoretical model.[180]

Brown and MacKay next evaluated how these disparities in algorithmic sophistication affected these retailers' prices. The game theoretical models described above predict that asymmetric pricing frequency (and asymmetric commitment) would result in the firms with more sophisticated pricing technology offering lower prices than the firms that price less often. The data from this study bear out that prediction. Firm A, which had the most sophisticated technology—allowing it to change its prices more frequently than its rivals—had the lowest prices of the five retailers.[181] Firms D and E, which had the lowest-quality pricing technology and could change prices only once a week, had the highest prices.[182] According to the authors, firms D and E charged prices that were more than 25% higher than the prices firm A charged for the exact same products. Firm C, possessing moderate pricing frequency, priced products approximately 10% higher than firm A.[183] This correlation between pricing frequency and price levels is one of the key predictions of the Brown and MacKay model.

To measure the effect of asymmetric pricing technologies on equilibrium prices, Brown and MacKay applied an econometric model to the data to estimate demand. The authors compared the observed price levels to counterfactual Bertrand-Nash prices, which they obtained by assigning firms symmetric price-setting technology and simulating the equilibrium. The authors estimated that algorithmic competition among these firms—each possessing varying levels of pricing technology—resulted in average prices more than 5% higher than if the firms had symmetric technologies.[184] Firm A, with the fastest technology, enjoyed substantial increases in both price and market share due to algorithmic competition, resulting in the highest gain in profits (22%).[185]

Despite these price increases, the estimated model predicted only a modest output reduction (around 1%) due to asymmetric algorithmic

179. *Id.* at 12–13.
180. *See id.* at 14.
181. *See id.* at 15.
182. *See id.*
183. *See id.*
184. *See id.* at 39.
185. *See id.* at 40.

competition.[186] While the decline in total welfare therefore is small, Brown and MacKay found that algorithmic competition leads to a significant wealth transfer from consumers to merchants. The model showed a decline in consumer surplus of 4.1% and an increase in firm profits of 9.6% due to asymmetric algorithmic competition.[187] The authors calculated that, if similar effects were realized across the personal care category in which all five retailers have significant shares, the switch from Bertrand competition to algorithmic competition would cost online consumers $300 million a year.[188]

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Economic models and emerging empirical evidence suggest that algorithmic pricing can harm consumers even in competitive markets where rivals do not collude. The rapid expansion of algorithmic pricing throughout the economy means that this consumer harm will be widespread and significant. When firms use algorithmic pricing to explicitly collude, antitrust law is an obvious remedy. But what should be the policy response when consumers are harmed by non-collusive conduct? The following Part addresses that question.

III. POLICY RESPONSES

When pricing strategies harm consumers, typical policy responses include antitrust enforcement and, if that fails, direct price regulation.[189] Despite its focus on pricing and competition, however, in practice antitrust law can reach only a select few types of pricing conduct, none of which are implicated by the non-collusive algorithmic pricing strategies described in the previous Part. Direct regulation therefore is likely to be the best solution for ameliorating the transfer of surplus from consumers to sellers that algorithmic pricing makes possible.

This is not the first time that advances in pricing technology have led to economic disruption. In the early twentieth century, the introduction of price displays, price tags, and new pricing strategies like loss leaders contributed to fierce price-cutting and a dangerous deflation that exacerbated the

186. *See id.*
187. *Id.*
188. *Id.*
189. *See, e.g.*, ORG. FOR ECON. COOP. & DEV., *supra* note 11, at 33–50 (reviewing potential responses to algorithmic tacit collusion, including competition law enforcement and price regulation).

economic shock of the Great Depression.[190] The policy response then was direct pricing regulation: legislation and industrial codes limiting price cutting.[191] We argue that direct regulation of a different type might be appropriate today as a new revolution in pricing technology is again reshaping the nature of competition.

This Part begins by exploring the possibility of using antitrust law to address the problems that non-collusive algorithmic pricing poses for consumers. It concludes that antitrust law's prohibitions do not reach this type of pricing conduct. The discussion then turns to a history of early twentieth-century pricing innovations and resulting regulatory reactions. It closes with a review of potential regulatory responses to non-collusive algorithmic pricing.

A. Antitrust & Pricing

While much of antitrust law is focused on prices, the specific types of pricing conduct it prohibits ultimately are quite narrow. Most famously, antitrust forbids firms from explicitly colluding on prices. Price-fixing, bid rigging, and market allocation agreements are per se unlawful under section 1 of the Sherman Act and are considered criminal conduct.[192] Explicitly collusive algorithmic pricing falls directly into this forbidden zone. For example, despite their novel use of technology, when sellers of wall art agreed to use their pricing algorithms to fix prices on the Amazon Marketplace, the legal theory the Department of Justice used to successfully prosecute them was the same applied to conspiracies hatched in the smoke-filled rooms of the early twentieth century.[193] Antitrust is therefore the best available tool for dealing with algorithmic price-fixing conspiracies.

But liability under section 1 of the Sherman Act, which bars price-fixing, requires that there be an agreement among the defendants.[194] It is challenging to craft an antitrust intervention when firms do not explicitly

190. *See* Cochoy et al., *supra* note 48, at 574 (arguing that in the period after World War I and through the Great Depression "a rapid development of 'price cutting' strategies" in the "grocery business . . . based on the use of batch sales, 'specials', and so on . . . led to the development of price wars that worsened the effect of the Great Depression.").

191. *Id.* at 597–99; *infra* Section III.B.1. A number of scholars have argued that this policy was misguided. *See, e.g.*, Romer, *supra* note 56 at 197 ("[T]he NIRA can best be thought of as a force holding back recovery . . . .").

192. *See* U.S. DEP'T OF JUST., *supra* note 42, at 1–2.

193. *See* U.S. Dep't of Just., *supra* note 12 (announcing a guilty plea in a scheme involving fixing "the prices of certain posters sold online through Amazon Marketplace" and quoting Assistant Attorney General Bill Baer as stating that the Antitrust Division "will not tolerate anticompetitive conduct, whether it occurs in a smoke-filled room or over the Internet using complex pricing algorithms").

194. *See In re* Text Messaging Antitrust Litig., 782 F.3d 867, 879 (7th Cir. 2015) ("Collusion is illegal only when based on agreement.").

collude. This is the case even when rivals employ parallel pricing conduct to reach a collusive price. Tacit collusion is not currently unlawful under the antitrust laws.[195] As described above, a number of scholars have argued that algorithmic pricing facilitates conscious parallelism, in their view necessitating a new look at ways that antitrust should adapt to bar tacit collusion.[196]

The conduct this paper focuses on—non-collusive algorithmic pricing—is even further removed from the explicitly collusive conduct section 1 prohibits. In the scenarios described in the previous Part, neither human agents nor algorithms are agreeing on prices.[197] Indeed, the firms in these markets may not even be choosing the same price; supracompetitive prices can be supported even when some firms are charging a lower price than others.[198] Section 1 conspiracy law simply has no bearing on this type of conduct.

In addition to its prohibitions on price fixing and bid rigging, antitrust specifically bars or restricts three other types of pricing conduct: predatory pricing, resale price maintenance, and certain forms of price discrimination. None of these rules address the challenges posed by non-collusive algorithmic pricing.

1. Predatory Pricing

Section 2 of the Sherman Act prohibits firms from unlawfully acquiring or maintaining monopoly power in a relevant market.[199] To prevail on a section 2 claim, a plaintiff must prove that a firm has monopoly power and that it either acquired or maintained that position unlawfully.[200] Predatory pricing is one form of unlawful conduct firms might use to gain or maintain a monopoly. The idea is that a big and powerful firm can use below-cost

195. *See id.* ("Tacit collusion . . . does not violate section 1 of the Sherman Act.").

196. *See supra* notes 44–45.

197. *See supra* Section II.B. A key condition for demonstrating collusion is the presence of an agreement. *See, e.g.*, *Text Messaging*, 782 F.3d at 879. Werden provides the following general principle regarding such agreements: "The existence of an agreement cannot be inferred from actions consistent with Nash, non-cooperative equilibrium in a one-shot game oligopoly model." Werden, *supra* note 125, at 779. Yet the Brown and MacKay model shows precisely how elevated prices can be sustained in a Nash, non-cooperative equilibrium of a one-shot oligopoly game. *See* Brown & MacKay, *supra* note 14, at 32–35.

198. *See* Brown & MacKay, *supra* note 14, at 3 (arguing that in "the case of asymmetric technology . . . firms with superior pricing technology have relatively lower prices, and all prices may be elevated relative to the Bertrand-Nash equilibrium").

199. *See* 15 U.S.C. § 2.

200. *See* United States v. Grinnell Corp., 384 U.S. 563, 570–71 (1966) ("The offense of monopoly under [section] 2 of the Sherman Act has two elements: (1) the possession of monopoly power in the relevant market and (2) the willful acquisition or maintenance of that power as distinguished from growth or development as a consequence of a superior product, business acumen, or historic accident.").

pricing to drive its smaller and less well-capitalized rivals out of business, thereby allowing it to raise prices to supracompetitive levels. Courts and enforcers are wary of predatory pricing claims because, at least in the short run, consumers benefit from the price war.[201] The bar therefore is high for plaintiffs in these cases. They must demonstrate that the defendant charged prices that were below some measure of its costs and that it had a "reasonable prospect" or a "dangerous probability" of recouping its losses after the predation period.[202] To prove recoupment, a plaintiff must show that the defendant's conduct could or did drive its rival(s) out of the market and that barriers to entry are sufficiently high that the defendant subsequently would be able to raise prices to a supracompetitive level for enough time to gain back the losses it incurred from pricing below cost.[203]

Predatory pricing may have a role to play in certain kinds of algorithmic pricing settings.[204] Lina Khan has argued, for example, that Amazon's pricing algorithm allows it to strategically undercut its rivals' prices.[205] The equilibrium analysis presented in this Article shows that algorithmic pricing may have the opposite effect, leading to increased prices for all firms. Predatory pricing theory is inapplicable to situations where pricing algorithms facilitate multiple sellers raising prices above the competitive level.

2. Resale Price Maintenance

For almost a century in the United States, federal antitrust law prohibited manufacturers from agreeing with retailers on resale prices for their

201. *See* Brooke Grp. Ltd. v. Brown & Williamson Tobacco Corp., 509 U.S. 209, 223 (1993) (Any exclusionary effect of above-cost pricing either "reflects the lower cost structure of the alleged predator . . . or is beyond the practical ability of a judicial tribunal to control without courting intolerable risks of chilling legitimate price cutting.").

202. *Id.* at 222–24 (holding that to prevail on a predatory pricing claim a plaintiff "must prove that the prices complained of are below an appropriate measure of its rival's costs" and "that the competitor had a reasonable prospect, or . . . a dangerous probability, of recouping its investment in below-cost prices").

203. *See id.* at 225–26 ("For recoupment to occur, below-cost pricing must be capable, as a threshold matter, of producing the intended effects on the firm's rivals, whether driving them from the market, or . . . causing them to raise their prices to supracompetitive levels within a disciplined oligopoly . . . . Determining whether recoupment of predatory losses is likely requires an estimate of the cost of the alleged predation and a close analysis of both the scheme alleged by the plaintiff and the structure and conditions of the relevant market.").

204. *See* Christopher R. Leslie, *Predatory Pricing Algorithms*, 97 NYU L. REV __ (forthcoming 2023) (demonstrating how pricing algorithms can facilitate predatory pricing).

205. *See* Lina M. Khan, *Amazon's Antitrust Paradox*, 126 YALE L.J. 710, 768–770 (2017) (describing how Amazon used its "pricing bots" to strategically undercut prices its rival Quidsi charged for diapers and other baby products, ultimately resulting in Quidsi being forced to sell itself to Amazon).

goods.[206] Under that regime, a producer of board games or knives or toilet paper could not directly control the prices retailers charged for those products. In a pair of cases in 1997 and 2007, the U.S. Supreme Court held that minimum and maximum resale price maintenance no longer would be treated as per se unlawful, but rather should be evaluated on a case-by-case basis under antitrust law's rule of reason.[207] Resale price maintenance remains per se unlawful under the laws of some states.[208]

It is possible that manufacturers' resale price maintenance policies could affect price levels in markets subject to non-collusive algorithmic pricing. If a manufacturer were unhappy with the prices some retailers charged for its products, either because it believed those prices were too high or too low, it could intercede, potentially upsetting the pricing structure that retailers' algorithms constructed. However, in situations where non-collusive algorithmic pricing has resulted in supracompetitive prices across retailers, it seems unlikely that manufacturers would employ resale price maintenance policies that reduce prices for consumers.

In any event, the restrictions federal and state antitrust laws place on resale price maintenance should not directly affect retailers' ability to engage in non-collusive algorithmic pricing, as long as their algorithms are not calibrated to take into account manufacturer-required price maximums or minimums.

3. Price Discrimination: The Robinson-Patman Act

The Robinson-Patman Act (RPA) prohibits firms from charging competing customers different prices for goods of "like grade and quality" or discriminating in any "allowance[s]" (typically advertising funds) they provide.[209] Enacted in 1936,[210] the RPA was intended to protect local retailers from encroaching chain stores that, due to their buying power, were

206. *See* Dr. Miles Med. Co. v. John D. Park & Sons Co., 220 U.S. 373, 394, 409 (1911) (holding that minimum resale price maintenance agreements violate the Sherman Act), *overruled by* Leegin Creative Leather Prods., Inc. v. PSKS, Inc., 551 U.S. 877 (2007); *see also* Albrecht v. Herald Co., 390 U.S. 145, 152–53 (1968) (finding a maximum resale price agreement per se unlawful under section 1 of the Sherman Act), *overruled by* State Oil Co. v. Khan, 522 U.S. 3 (1997).

207. *See Leegin*, 551 U.S. at 907 (overturning *Dr. Miles*' per se rule and subjecting minimum resale price agreements to the rule of reason); *Khan*, 522 U.S. at 22 (overturning *Albrecht*'s per se rule against maximum resale price maintenance agreements and subjecting such agreements to the rule of reason).

208. *See* Matthew L. Powell, *A Primer on Resale Price Maintenance*, 96 MICH. BAR J. 20, 21 (2017) ("[A] number of states continue to treat vertical price fixing as per se illegal under state laws . . . .").

209. 15 U.S.C. § 13(a), (c).

210. 49 Stat. 1526 (1936).

able to purchase goods at a lower price and in turn charge lower prices to consumers.[211]

Like restrictions on predatory pricing and resale price maintenance, it is possible that the RPA could affect algorithmic pricing policies. It might be unlawful, for example, for a manufacturer to employ a pricing algorithm that charged competing customers different prices for the same goods. But such prohibitions would not ameliorate the generalized harm consumers will suffer from the higher prices caused by pricing algorithms in competitive markets.

In sum, antitrust currently places only limited restrictions on firms' pricing conduct. And its prohibitions on predatory pricing and certain forms of resale price maintenance and price discrimination do not reach the type of consumer harm we identify. In the absence of any obvious antitrust solution, direct regulation may the best way to prevent a massive redistribution of wealth from consumers to sellers.

B. Pricing Regulation

Pricing regulation has a checkered history in the United States. Outside of heavily regulated industries like electric utilities, pricing regulation is generally disfavored among contemporary economists and policy makers.[212] But that has not always been the case, especially when innovations in pricing technology have upended markets. Algorithmic pricing represents a sea change in pricing technology that is already redefining the relationship between sellers and customers. This type of disruption is not without precedent, however. In the early part of the twentieth century, another set of pricing innovations transformed retail markets, ultimately leading to regulation to correct what were seen as existential threats to the economy.

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211. *See* Owen M. Fiss, *The Supreme Court, 1978 Term*, 93 HARV. L. REV. 1, 239 (1979) ("The Robinson-Patman Act was enacted to eliminate large buyers' use of purchasing power to exact price concessions and thereby gain an advantage over smaller businesses.").

212. *See, e.g.*, Rockoff, *supra* note 47, at 409 ("[E]conomists are generally opposed to [price controls] . . . ."); ORG. FOR ECON. COOP. & DEV., *supra* note 11, at 49–50 ("[P]rice regulations not only reduce incentives to innovate or to provide high-quality products, but could actually result in higher prices by creating a focal point for collusion in digital markets that would otherwise be competitive."). *See also* Herbert Hovenkamp, *Antitrust and Platform Monopoly*, 130 YALE L.J. 1952, 1971, 1989 (2021) (explaining that the power transmission portion of an electric utility's business is a natural monopoly and observing that "[t]he traditional prescription is . . . to regulate the prices that natural monopolies charge").

1. Disruptive Pricing Technologies: Price Displays and Discounting Strategies

For centuries prior to the twentieth century, most retail prices were decided on a customer-by-customer basis. Retailers kept track of what they paid for goods and determined prices based on those costs.[213] Prices were not listed or displayed, so individual consumers could bargain with sellers, and prices fluctuated constantly.[214] This lack of pricing transparency also meant that comparison shopping among retailers was nearly impossible for consumers.[215]

A number of factors contributed to the rapid decline of this pricing regime in the early twentieth century. These included the development of new pricing technologies, like price cards, and the novel pricing strategies that these technologies made possible, like batch sales and loss leaders.[216] The early 1920s saw an explosion of new price display technologies.[217] The Clamp-Swing Price Card Holder, for example, was a metal device that was attached by means of a metal clamp to a shelf below the products for sale. It listed the product's price and allowed the customer to grab an item off the shelf without knocking down the display.[218] Clamp-Swing and several competitors, including F.M. Zimmerman, also developed price displays designed to facilitate batch sales.[219] The Clamp-Swing batch sale device had two parts: one that described the amount of a good for sale and the other that stated the price.[220] This design allowed shopkeepers to easily display an offering of five pounds of potatoes for fifty cents or three cans of corn for twenty-five cents and to quickly change those terms at any time by replacing either the amount or the price card.[221]

Pricing card companies created similar displays for "specials," which allowed retailers to implement pricing strategies based on loss leaders.[222]

213. *See* Cochoy et al., *supra* note 48, at 577 (At the turn of the twentieth century, retailers would mark goods with their costs and use the cost "as a base for bargaining with each individual customer").

214. *See id.* ("[P]rice-cutting was both systematic and limited: every transaction would include a price negotiation often ending in a price reduction . . . .").

215. *See id.* ("[P]rice comparisons . . . were effectively restricted.").

216. *Id.* at 577–86 (describing the development of new price-tag devices after World War One and their facilitation of innovative retail pricing strategies, including batch sales, loss leaders, and specials).

217. *See id.* at 579 ("From the early 1920s, prices spread on the shelves, thanks to the rapid development of new price tag devices promoted by several companies . . . .").

218. *History of Clamp-Swing Pricing Company*, CLAMP-SWING PRICING CO., http://www.clampswing.com/about-us.php [https://perma.cc/P9SM-F249] (describing Clamp-Swing Price Card Holders and noting that they "created a minor revolution in the 1920's in the price marking field").

219. Cochoy et al., *supra* note 48, at 579–80.

220. *Id.* at 580.

221. *See id.*

222. *See id.* at 582.

The idea was to strategically pick certain goods and assign them a low price to get customers into the store, where they might buy additional items at a more profitable price.[223] If well executed, the loss-leader strategy could convince consumers that the retailer's prices were low overall.

These new pricing technologies and strategies had several important ramifications. First, as Franck Cochoy, Johan Hagberg, and Hans Kjellberg have argued, retail prices shifted from being flexible and set on an ad hoc basis for individual customers to being fixed for all of a seller's customers.[224] Second, public pricing displays made comparison shopping much easier for consumers.[225] For the first time, retailers felt sustained pricing pressure based not only on their own costs, but also on their competitors' prices.[226] Third, this new competitive environment, combined with pricing strategies that emphasized discounting—through batch sales and specials—led to a period of intense retail price reductions and deflation.[227]

These changes were taking place in the period leading up to and during the first years of the Great Depression, exacerbating what were seen as the perils of systematic price cutting and "cut-throat competition."[228] Contemporary policy experts warned against the evils of overly aggressive price competition.[229] Speaking at a National Recovery Administration meeting in 1934, the agency's leader, General Hugh S. Johnson, asserted that among the goals of the National Recovery Act was "[a] more uniform and equitable rule of national price stabilization in those cases where it is necessary to maintain wages at a decent standard against the certain results of predatory and cut-throat competition."[230] Earlier, in his Second Fireside

223. *See id.*

224. *Id.* at 578 ("During the bargaining era, prices were fully flexible [and] were adjustable, but at the individual level only . . . . With the new price display regime, prices were largely available . . . but at the expense of becoming more fixed . . . . [P]rices were now the same for every customer and worked according to a new 'take it or leave it' logic.").

225. *See id.* at 577 ("[O]pen prices . . . offer[ed] both commercial appeal and a basis for price comparison and competition.").

226. *Id.* at 579 ("While the displayed prices might be fixed within the store during any given day, their fixity was challenged . . . from the outside, via price competition . . . .").

227. *Id.* at 586 ("[A]t the level of the aggregated economy . . . [p]rice cuts started a vicious circle of price competition that contributed, if not to creating, at least to accelerating deflation.").

228. *See id.* at 588; Ellis Hawley, THE NEW DEAL AND THE PROBLEM OF MONOPOLY 13 (1966) (explaining that some contemporary "industrialists and pro-business planners" argued that the depression "was due mostly to irresponsible 'chiseling' and 'cutthroat competition'").

229. *See* Bruce E. Kaufman, *John R. Commons and the Wisconsin School on Industrial Relations, Strategy and Policy*, 57 INDUS. AND LABOR RELS. REV. 3, 20 (2003) ("The second part of the explanation for the Depression—shared by everyone, . . . was that its severity and duration were measurably worsened by the macroeconomic process of destructive competition.").

230. *Text of Gen. Hugh S. Johnson's Address at Opening of NRA Meeting in Capital*, N.Y. TIMES (Feb. 28, 1934).

Chat, President Roosevelt promised that "measures will . . . be proposed which will attempt to . . . prevent cut-throat competition."[231] Manufacturers were especially unhappy about retailers' new price-cutting strategies, which they viewed as undermining public confidence in the true value of their goods.[232]

Within years of the introduction of these novel pricing technologies and strategies, a widespread sentiment developed that price-cutting and deflation were out of control and that legislative or regulatory responses were necessary to stabilize the situation. Manufacturers supported legislation in the 1910s, 1920s, and early 1930s that would have allowed them to engage in resale price maintenance, which at the time was per se unlawful under the antitrust laws.[233] In 1927, the FTC launched an "economic investigation" into "the practice of resale price maintenance" that was supported by the U.S. Chamber of Commerce.[234] The investigation's goals included determining "the causes and motives for price cutting" and "how far price cutting has eliminated manufacturers and distributors from business."[235]

Ultimately, these efforts at addressing falling prices through resale price maintenance legislation failed to come to fruition. Instead, the new Roosevelt administration attacked the problem through the industrial codes of the National Recovery Administration. The National Industrial Recovery Act of 1933 invited trade and industrial organizations to submit to the President for his approval "codes of fair competition."[236] The Act stated that "[w]henever the President shall find that destructive wage or price cutting or other activities contrary to the policy of this title are being practiced in any trade or industry," such that the President deems it "essential to license business enterprises in order to make effective a code of fair competition," no firms could carry on business in that industry absent a license.[237]

231. President Franklin D. Roosevelt, Second Fireside Chat (May 7, 1933).

232. *See* Cochoy et al., *supra* note 48, at 590 (noting the sentiment in the early 1930s that "manufacturers . . . lost goodwill because low prices were raising doubts as to the real value and quality of their products").

233. *See* Comment, *Resale Price Maintenance and the Anti-Trust Laws*, 18 U. CHI. L. REV. 369, 371 (1951) (From 1914 to 1932, "repeated efforts were made to pass federal legislation legalizing resale price maintenance agreements in interstate commerce").

234. *See* FED. TRADE COMM'N, MEMORANDUM OF ECONOMIC INVESTIGATION OF F.T.C. 1, 8–9 (1927), https://www.ftc.gov/system/files/documents/public_statements/673541/19271212_myers_memorandum_re_economic_investigations_of_ftc.pdf [https://perma.cc/P87D-K75U].

235. *Id.* at 16.

236. National Industrial Recovery Act, Pub. L. No. 73-67, tit. 1, § 3, 48. Stat. 195, 196 (1933), *invalidated by* A.L.A. Schechter Poultry Corp. v. United States, 295 U.S. 495 (1935).

237. *Id.* tit. 1, § 4(b).

More than 500 industries ultimately adopted these codes, most of which limited price cutting and set minimum prices.[238] For example, the Code of Fair Competition for the Cotton Textile Industry stated that the Cotton Textile Industry Committee would make recommendations to the NRA administrator regarding "the naming and reporting of prices which may be appropriate . . . to prevent and eliminate unfair and destructive competitive prices and practices."[239] The Code of Fair Competition for the Electrical Manufacturing Industry required producers to submit current pricing information and barred them from charging prices below those submitted.[240] Many of these codes forbade producers to charge prices below their costs.[241] The NIRA exempted these codes from the antitrust laws.[242]

The U.S. Supreme Court invalidated the NIRA in 1935.[243] But, for two years, the Act transformed pricing policy in the United States in an attempt to reverse the deflationary trends caused in part by the new pricing technologies and strategies developed in the 1910s and 1920s. This episode demonstrated the potential for a swift regulatory response to the perceived negative consequences of advances in pricing techniques.

Algorithmic pricing presents a very different challenge than that posed by price cards and loss leaders. Rather than lowering prices for consumers, the concern is that algorithmic pricing is raising retail prices. Therefore, even if one believed that industry-wide price floors and prohibitions on discounting were effective policies in the 1930s, those strategies are certainly not appropriate for the current era. Instead, policies that could reduce prices—price caps and direct price controls—might be considered.

2. Price Controls

Despite a general policy preference for free market principles, there is a robust history of price controls in the United States, especially during

238. *See* Harold L. Cole & Lee E. Ohanian, *New Deal Policies and the Persistence of the Great Depression: A General Equilibrium Analysis*, 112 J. POL. ECON. 779, 784 (2004) ("[m]inimum price was the most widely adopted provision" in the Codes of Fair Competition.).

239. 1 NAT'L RECOVERY ADMIN., CODES OF FAIR COMPETITION, NOS. 1–57, at 17 (1933), http://moses.law.umn.edu/darrow/documents/codes_fair_competion_vol_1.pdf [https://perma.cc/76H9-WWL5].

240. *Id.* at 49.

241. *See, e.g.*, *id.* at 653 (Code of Fair Competition for the Compressed Air Industry); *see id.* at 659 ("No employer shall sell or exchange any product of his manufacture at a price or upon terms or conditions that will result in the customer paying for the goods received less than the cost to the seller . . . .").

242. *See* National Industrial Recovery Act, Pub. L. No. 73-67, tit. 1, § 5, 48. Stat. 195, 198 (1933).

243. *See* A.L.A. Schechter Poultry Corp. v. United States, 295 U.S. 495, 541–42 (1935) (striking down the NIRA on the ground that it represented an unconstitutional delegation of legislative power to the President).

emergency periods. For example, price controls were implemented during both World Wars and the Korean War, periods where there was widespread concern about rampant inflation.[244] Other familiar forms of price controls include the minimum wage (setting a floor on the price of labor), rent control (setting a ceiling on the price of housing), and anti-usury laws (setting a ceiling on interest charged on loans). In the 1970s, the federal government twice placed price caps on gasoline.[245]

The most sweeping recent example of a price control regime in the United States is the Nixon administration's New Economic Policy, which froze prices and wages for a ninety-day period in 1971 and again in 1973.[246] In 1970, Congress passed the Economic Stabilization Act, which gave the President the authority to "issue such orders and regulations as he may deem appropriate to stabilize prices, rents, wages, and salaries at levels not less than those prevailing on May 25, 1970."[247] The Nixon administration enacted the New Economic Policy as a response to fears about out-of-control inflation and rising unemployment.[248] It created the Cost of Living Council, which oversaw two components: the Price Commission—which dealt with price increases—and the Pay Board—which dealt with wage increases. The New Economic Policy initially had a great deal of popular support and was viewed as a bold response to a growing national crisis.[249] The Policy led to some short-term political successes for President Nixon, but ultimately it was judged by many to have failed at its central task of controlling inflation.[250]

Price controls continue to be considered a viable regulatory tool. Indeed, price controls recently have been proposed as a way to address the high costs of certain drugs. In 2021, the U.S. House of Representatives reintroduced a bill that would require the U.S. Department of Health and Human Services to negotiate maximum prices for certain drugs, including

244. *See* Rockoff, *supra* note 47, at 409, 411.

245. *Id.* at 409–10.

246. *See generally* George P. Schultz and Kenneth W. Dam, *Reflections on Wage and Price Controls*, 30 INDUS. AND LABOR RELS. REV. 139 (1977) (analyzing the Nixon administration's price and wage control policies in the years 1971–74).

247. Economic Stabilization Act of 1970, Pub. L. No. 91-379, § 202, 84 Stat. 799 (1970).

248. *See* Exec. Order No. 11,615, 36 Fed. Reg. 15,727 (Aug. 15, 1971) (stating that the purpose of the Order is to "stabilize the economy, reduce inflation, and minimize unemployment"); Richard M. Nixon, President, Address to the Nation Outlining a New Economic Policy: "The Challenge of Peace" (Aug. 15, 1971), https://www.presidency.ucsb.edu/documents/address-the-nation-outlining-new-economic-policy-the-challenge-peace [https://perma.cc/2KDA-CAJR] ("The time has come for a new economic policy for the United States. Its targets are unemployment, inflation, and international speculation.").

249. *See* Rocco C. Siciliano, *The Nixon Pay Board—A Public Administration Disaster*, 62 PUB. ADMIN. REV. 368, 368 (2002) (describing the New Economic Policy as a "bold—perhaps drastic—move" that "delighted the country").

250. *Id.* at 373 (arguing that the New Economic Policy "stymied inflation through the [1972] election," but that "[t]he nation suffered for it" and "by 1974 inflation was on a rampage").

insulin and drugs that do not face generic competition.[251] The bill mandates that the negotiated price for these drugs not exceed either 120% of the price paid in six countries that have drug price controls or, if pricing information from those countries in unavailable, 85% of the U.S. average manufacturer price.[252]

It is likely unsurprising that most economists view price controls with disfavor.[253] In the orthodox view, direct government intervention in markets is typically ineffective and results in dangerous economic distortions such as shortages of a good whose price is capped or surpluses of a good whose price is supported by a price floor.[254] Price controls also often lead to rationing and black markets.[255] If they support them at all, economists view price controls as appropriate only during short-term emergencies.[256]

The higher prices algorithms can cause are likely neither an emergency (compared to wartime price gouging, for example), nor short-term, as it seems likely that algorithmic pricing is here to stay. Further, price controls are a blunt instrument that would prove unwieldy in addressing the thousands of markets and millions of products potentially affected by algorithmic pricing.[257] A price control regime would require standing up a new bureaucracy to set prices and would result in a long-term, massive expansion of the federal government's role in the market. These ramifications counsel against price controls and toward a more targeted solution, one that would be directed specifically at markets where algorithmic pricing is leading to higher prices and reducing consumer welfare. In short, the most effective approach to the challenges algorithmic pricing raises likely is one that would regulate the algorithms themselves.

C. Regulating Algorithmic Pricing

Pricing algorithms create several risks for competition and consumers, some of which antitrust law can address and some of which might require regulatory solutions. Firms can use pricing algorithms to facilitate explicit

251. Elijah E. Cummings Lower Drug Costs Now Act, H.R. 3, 117th Cong. §§ 1191–92 (2021).

252. *Id.* §§ 1191(c)(3), 1194(c).

253. *See, e.g.*, Rockoff, *supra* note 47, at 409 ("[E]conomists are generally opposed to [price controls] . . . .").

254. *Id.* ("The reason most economists are skeptical about price controls is that they distort the allocation of resources.").

255. *Id.* at 409–10.

256. *Id.* at 409 (asserting that economists generally oppose price controls "except perhaps for very brief periods during emergencies").

257. One source estimated Amazon.com to have an inventory of 12 million products. *See* Seamus Breslin, *15 Amazon Statistics You Need to Know in 2022*, REPRICEREXPRESS, https://www.repricerexpress.com/amazon-statistics/ [https://perma.cc/P4AG-VAKG]. Including third-party Marketplace sellers, this figure balloons to over 350 million products. *Id.*

collusion, like price-fixing. These types of schemes are subject to criminal sanction under section 1 of the Sherman Act.[258] Pricing algorithms also might allow firms to more effectively engage in tacit collusion, conduct that currently falls outside the bounds of antitrust law.[259] As discussed above, scholars have proposed expanding the antitrust laws to reach tacit collusion and also have recommended regulatory interventions.[260] There is no question that the conduct this Article focuses on—non-collusive algorithmic pricing competition—falls outside the reach of the antitrust laws, even broadly conceived. Still, pricing algorithms can harm consumers by allowing competing firms to charge supracompetitive prices even absent collusion.

As explained above, the two key characteristics that empower pricing algorithms to facilitate higher prices are asymmetries in pricing frequency and the ability to commit to an automated price response to changes in rivals' prices. Accordingly, an effective regulatory approach might be based on eliminating one or both of these characteristics. This would mean either barring asymmetries in pricing frequency or prohibiting firms from incorporating rivals' pricing in their algorithms. The following subparts discuss these interventions.

1. Regulating Pricing Frequency

Recall that when variations in the sophistication of pricing technologies create asymmetries in pricing frequency, firms will adopt a leader-follower pricing pattern.[261] Firms with more advanced technology will undercut firms with inferior technology and all firms will price above the competitive level.[262] The key to this arrangement is the understanding among firms with inferior pricing technology that whatever price they set for a particular period can be beaten by firms that price more often. Thus, their incentive to compete on price is blunted. But if the asymmetry were eliminated, firms in healthy markets would resume vigorous price competition.[263]

One way to achieve this goal would be to regulate when firms can set prices.[264] For example, regulations could require firms to price only once a

258. *See supra* note 42.

259. *See In re* Text Messaging Antitrust Litig., 782 F.3d 867, 879 (7th Cir. 2015) ("Tacit collusion . . . does not violate section 1 of the Sherman Act.").

260. *See supra* notes 44–45 and accompanying text.

261. *See supra* Section II.B.1.

262. *See supra* Section II.B.1.

263. *See supra* Section II.B.1.

264. Scholars have proposed other scenarios in which it could be beneficial to regulate when firms can change their prices. *See, e.g.*, Aaron S. Edlin, *Stopping Above-Cost Predatory Pricing*, 111 YALE L.

day or only once a week and to do so at the same time every day or every week. In that scenario, it would be difficult to establish a leader-follower pattern and firms would be incentivized to propose their best price every period. Algorithms still would have a role to play in this regulatory regime: firms could program their algorithms to account for the same factors they do now, including supply and demand, market prices, consumer preferences, and seasonality. And firms with superior technology still might win more customers. But sellers with inferior pricing technology would no longer be de-incentivized to cut prices and, in well-functioning markets, all firms would charge prices closer to the competitive level.

Further, though regulating pricing frequency would not directly address the second key feature of algorithms—commitment to react to rivals' price changes—it could eliminate the ability of firms to employ strategies that appear competitive but generate higher prices, drawing a clearer line between competitive and collusive conduct. By making the time between price changes long enough, firms' algorithms would have to incorporate large, discrete punishments to support higher prices. These punishments would be easily detectable by regulators and consumer groups.

Regulators have employed restrictions on asymmetric pricing before. In both Austria and Western Australia, governments imposed regulations on the frequency of price changes in retail gasoline markets.[265] The goal of these regulations was to decrease price volatility in markets where price changes were common and consumers wanted increased price transparency.[266] The Austrian law, enacted in 2009, limited gas stations to increasing their prices only once a day, though they could decrease prices as often as they wanted.[267] Price increases could be initiated only at certain times of day, depending on the hours the gas station was open. So, for example, gas stations that were open twenty-four hours a day had to make any price increases at midnight.[268] In 2011, the law was revised to require all gas stations to make any price increases once a day at noon.[269] The

J. 941, 966 (2002) (proposing a price freeze to prevent incumbent monopolists from engaging in predatory pricing to deter entry); Gal, *Limiting Algorithmic Cartels*, *supra* note 115 at 33–36 (proposing that when algorithmic coordination leads to supra-competitive prices one competitor's price should be frozen so that its rivals can lower their prices and capture the price-frozen firm's customers).

265. *See* Dewenter & Heimeshoff, *supra* note 61, at 5 (describing regulations restricting the frequency of price changes in retail gasoline markets in Austria and Western Australia).

266. *See, e.g.*, *Legislative Framework*, FUELWATCH, https://www.fuelwatch.wa.gov.au/about/legal [https://perma.cc/M9UJ-33MQ] (noting Western Australian "motorists' frustration at intra-day price fluctuations").

267. *See* Dewenter & Heimeshoff, *supra* note 61, at 5 (describing 2009 Austrian pricing regulation for gas stations).

268. *Id.*

269. *Id.*

Austrian law also mandated that every gas station post its prices on a public website so consumers could comparison shop.[270]

The pricing program in Western Australia was instituted pursuant to the Petroleum Products Pricing Act 1983, as amended in 2000–2001.[271] Under the auspices of this law, the Western Australian government created the FuelWatch program, which was designed to increase price transparency for consumers.[272] These rules require gas stations to notify regulators of their pricing for the following day by 2 p.m. every day; to keep prices the same for every twenty-four-hour period starting at 6 a.m.; and to display their prices on "roadside price boards."[273] These prices are also posted on the FuelWatch website.[274]

While these Austrian and Western Australian regulations succeeded in increasing pricing transparency for consumers, there was concern among economists that they might also raise the likelihood of collusion among gas stations, leading to higher prices. Two experimental studies predicted that the Austrian law would result in increased gas prices, though one of those studies found that the Western Australian regulation would not have a significant impact on pricing.[275] An empirical study of both sets of regulations, however, concluded that gas prices in Austria fell after the pricing regulation was implemented, and that there were no significant changes to gas prices in Western Australia due to the FuelWatch program.[276]

Restrictions on when firms price have been proposed for other markets where advances in technology appear to harm consumers. Eric Budish, Peter Cramton, and John Shim have argued that what they call the high-frequency trading "arms race" in financial markets results in increased costs to provide liquidity and that those costs are passed on to customers in the form of higher bid-ask spreads on trades.[277] They trace this problem to what they describe as "a basic flaw in the design of modern financial exchanges:

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270. *Id.*

271. *See* FUELWATCH, *supra* note 266.

272. *Id.* (explaining how the FuelWatch program strives "to achieve it[s] goal of price transparency").

273. *Id.*

274. FUELWATCH, https://www.fuelwatch.wa.gov.au/ (last visited June 6, 2022).

275. *See* Dewenter & Heimeshoff, *supra* note 61, at 4 (describing experimental studies).

276. *Id.* at 15 (describing results of empirical study showing that the Austrian pricing rule "has a significant negative effect on fuel price levels" but that the authors could not "find statistically significant effects of [the Western Australian] fuel price regulation on price levels"). *But see* David P. Byrne & Nicolas de Roos, *Learning to Coordinate: A Study in Retail Gasoline*, 109 AM. ECON. REV. 591, 592–93 (2019) (reporting results of empirical study finding a "substantial increase in [retail gas stations'] margins" in wake of Western Australian pricing regulation).

277. *See* Eric Budish, Peter Cramton & John Shim, *The High-Frequency Trading Arms Race: Frequent Batch Auctions as a Market Design Response*, 130 Q.J. ECON. 1547, 1554 (2015) (arguing that "arbitrage rents" caused by high-frequency trading "increase the cost of liquidity provision" and that such costs are "incorporate[d] . . . into the bid-ask spread that [trading firms] charge").

continuous-time trading."[278] Today's financial exchanges operate using a continuous limit order book design, which allows trades to be made continuously and at any time.[279] Firms are competing to trade ever-faster, and indeed speeds are increasing. But this dimension of competition, the authors assert, is not beneficial for most investors and leads to increased liquidity costs.[280] Because competition will not address the issue, the authors propose regulating when firms can trade. Rather than allowing continuous trading, they argue for "frequent batch auctions," which happen at discrete times during the trading day. In this system, all trade requests that arrive during a particular time period would be treated as having arrived at the same time for purposes of the auction.[281] As a result, speed would matter less and firms would compete purely on price, lowering costs for consumers.[282]

In addition to the concerns about collusion noted above, policy makers and firms might object to this type of regulatory intervention on the ground that it reduces incentives to innovate in pricing technologies. As we argue below, however, we believe that developments in pricing algorithms represent what we call "extractive innovation" that, while undeniably constituting technological progress, harms rather than helps consumers.[283] Accordingly, policy makers should be less concerned about regulations that de-incentivize advancements in pricing algorithms than they would be about other policies that blunt innovation incentives. Recall, too, that currently firms with inferior pricing technology generally have no incentive to upgrade.[284] These firms typically prefer to have less sophisticated

278. *Id.* at 1549.

279. *Id.*

280. *Id.* at 1555 ("[C]ompetition in speed does not fix the underlying problem . . . .").

281. *See id.* at 1549.

282. *Id.* at 1556 (arguing that frequent batch auctions "reduce[] the value of a tiny speed advantage, which eliminates the arms race" and results in traders being "forced to compete on price instead of speed").

283. Ramsi Woodcock has introduced the concept of "extractive technologies," which he defined as "new technologies that facilitate the related practices of price discrimination [and] dynamic pricing." Letter from Ramsi Woodcock, Assistant Professor of L., Univ. of Ky. J. David Rosenberg Coll. of L., to Off. of the Sec'y, Fed. Trade Comm'n (Oct. 14, 2018) (on file with authors). Our conception of "extractive innovation" is broader than Woodcock's categorization. We define "extractive innovation" as any technological advance that harms rather than helps consumers by transferring wealth from consumers to sellers. Pricing algorithms are the example we explore in this Article, but we believe that "extractive innovation" could describe a range of anti-consumer innovations.

284. *See* Brown & MacKay, *supra* note 14, at 26 (explaining that a firm with inferior pricing technology "has a disincentive to upgrade its technology to match that of" a firm with superior pricing technology).

technology because the disparity among rival technologies creates the asymmetries that allow all firms to price above the competitive level.[285]

Another likely objection to this type of regulation is that limiting when firms can price restricts their ability to be nimble and respond quickly to changing market conditions. This argument is not without merit. In a market with competitive prices, enabling firms to adjust prices as often as they like would allow them to efficiently respond to changes in supply and demand, which, in some cases, can yield lower costs and lower prices to consumers.[286] But, as Brown and MacKay demonstrate, asymmetries in pricing algorithms distort prices away from competitive levels. Firms with superior technologies re-price more often—in some cases, many times a day—but can still price above the competitive level.[287] In markets where non-collusive algorithmic pricing has this effect, consumers would benefit from increased competition and lower prices if firms were required to price simultaneously.

Further, in many cases, variation in supply and demand is predictable in advance. For example, in ridesharing markets, demand increases during rush hour and after sporting events.[288] In these markets, firms may be permitted to choose a price schedule to specify how rates change over time—e.g., every thirty minutes—but this schedule would be set at a lower frequency, such as once a day or once a week.[289] Such a regulation would prevent asymmetries in frequency that soften price competition. Though firms pricing in this manner would not be able to adjust to *unpredictable* intra-day swings in demand and supply, we suspect that, in most cases, consumers would benefit.

A concern with any new regulatory program is its expense and administrability. In some respects, restrictions on asymmetric pricing frequency would be relatively easy to enforce. Regulators would not need

285. *Id.* (concluding that "asymmetry is essential to generating higher prices," and if a firm with inferior technology upgrades it so it can "update prices at the same frequency" as its rival, "then the equilibrium prices return to the Bertrand-Nash equilibrium").

286. *See* Alexander MacKay, Dennis Svartbäck & Anders G. Ekholm, *Dynamic Pricing and Demand Volatility: Evidence from Restaurant Food Delivery* (Harv. Bus. Sch., Working Paper, No. 23-007, 2022), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4164271.

287. *Id.* at 9–11, 39–40.

288. *See* Shan Jiang, Le Chen, Alan Mislove & Christo Wilson, *On Ridesharing Competition and Accessibility: Evidence from Uber, Lyft, and Taxi*, *in* WWW '18: PROCEEDINGS OF THE 2018 WORLD WIDE WEB CONFERENCE, 863, 867 (International World Wide Web Conferences Steering Committee, Republic and Canton of Geneva, Switzerland 2018), https://dl.acm.org/doi/pdf/10.1145/3178876.3186134 [https://perma.cc/GVG6-TT2D] (observing that in San Francisco and New York City "there are two daily peaks" for supply and demand of Uber and Lyft cars, which "correspond[] to morning and evening rush hour"). The authors also note that there was a "sudden drop in supply and increase in demand, and corresponding increase in price" in New York City on February 5, 2017, which the authors "hypothesize . . . were caused by the Super Bowl." *Id.* at 866.

289. In a key distinction from commitment through an algorithm, prices would not adjust within a day to reflect the prices of rivals.

to take on the time-consuming task of carefully evaluating the functionality of individual firms' algorithms; they would only have to police when pricing takes place. It would not be easy to evade these regulations, though the regulator would need to expend resources monitoring the markets it oversees for compliance. Challenges presented by this type of regulation include identifying markets affected by algorithmic pricing and choosing an appropriate pricing frequency for each market. In each identified market, regulators would need to determine a schedule, or maximum frequency, for when firms can adjust prices. The goal would be to limit the frequency sufficiently to increase competition, while still allowing prices to adjust to changing market conditions. We conjecture that, for many consumer products, limiting price changes to once per day would enhance competition and not generate significant costs. However, making these determinations could be difficult and resource-intensive.

Nonetheless, the Austrian and Western Australian experiences restricting pricing frequency for retail gas demonstrate that this type of regulatory intervention can be implemented successfully.[290] The goals of those programs (increased transparency) were different than the aims such a regulatory intervention would have for markets subject to algorithmic pricing (returning prices to competitive levels).[291] But these real-world examples of regulatory regimes established to limit asymmetries in pricing frequency provide a road map for how such regulations could be developed and enforced in markets where algorithmic pricing harms consumers. Though these harms can occur in many diverse markets, the economic analysis suggests that the potential harm is greatest where the asymmetries in technology—in terms of relative pricing frequency and the ability to monitor and respond to rivals—are largest, and where a small number of firms hold a substantial technological advantage over their rivals.

2. Prohibiting Reliance on Rivals' Prices

Another regulatory intervention that likely would ameliorate the consumer harm non-collusive algorithmic pricing causes is to bar firms from incorporating rivals' prices in their algorithms. Asymmetric pricing capabilities are a problem only to the extent that firms with superior pricing technology can reference and undercut their competitors' prices. If that practice were outlawed, concerns about asymmetries in pricing frequency and commitment would recede. Pricing algorithms still would have a great deal of data to work with even without rivals' prices, including supply and

290. *See supra* notes 265–276 and accompanying text.
291. *Id.*

demand conditions, consumer characteristics and preferences, and seasonal conditions, such as the time of year and time of day a purchase is made.[292] And to the extent firms are concerned about responding quickly to market conditions, this intervention would allow re-pricing at any time and with any frequency.

The downside to this proposal is that it might reduce firms' ability to compete on price. Firms typically compete on a variety of product characteristics, but especially price.[293] Economic theory indicates that sophisticated firms can predict the prices that their rivals will choose, leading to competitive prices even when firms cannot actually observe rivals' prices.[294] These predictions require detailed knowledge about demand and rivals' costs, however. In practice, firms do not always have such rich knowledge and may rely on the information obtained from observed prices.[295] Whether the loss of this information would raise or lower prices is ambiguous, but it is possible that it would cause some firms to increase prices.[296]

Another objection to this intervention is that it would be difficult to police. Regulators would have relatively easy visibility into *when* firms price, simplifying enforcement of a regulation barring asymmetric pricing frequency, but it would be difficult for them to determine *how* firms are pricing and if an algorithm is referring to rival firms' prices. Enforcement likely would require firms to submit their algorithms to the relevant regulator to ensure that they are not relying on competitors' prices.[297] Absent such a mandate, firms will have a strong incentive to evade the regulation so they can gain market share and charge supracompetitive prices. Enforcing this type of regulation would require standing up a new bureaucracy to review pricing algorithms, increasing the size, power, and expense of government.

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292. *See* Ezrachi & Stucke, *supra* note 2, at 1780 ("Pricing algorithms . . . optimiz[e] the price based on available stock and anticipated demand . . . ."); Harrington, *supra* note 7, at 341 (explaining that a pricing algorithm's inputs "could include a firm's cost, inventory, day of the week, and past prices").

293. *See* FED. TRADE COMM'N, *supra* note 63, at 5 ("[P]rice is usually the principal basis for competition and consumer choice.").

294. TIROLE, *supra* note 149, at 206.

295. In our proposal, we would allow firms to indirectly respond to historical prices by tuning the parameters of their algorithms. This would, in principle, lead to competitive prices in markets where demand and supply conditions are stable over time, but may not do so if conditions fluctuate often.

296. For example, some firms may use the price of rivals to update their predictions on how costly it is to provide after-sale service to customers. Without this information from rivals, a risk-averse firm may charge more at the point of sale to account for this uncertainty.

297. A relevant question is whether firms could hire enough employees to monitor and manually adjust prices in a manner similar to an algorithm. Given the vast number of products sold online by individual retailers, we do not find this possibility particularly realistic. *See supra* note 257 (estimating that hundreds of millions of products are sold on the Amazon Marketplace).

Indeed, some scholars have advocated for the creation of a centralized algorithm regulator.[298] Such an entity would oversee a large body of algorithms, including those that set bail, determine insurance rates, choose among job candidates, and suggest potential romantic partners. In many cases, this regulator would be tasked with rooting out pernicious racial and gender bias in algorithms.[299] But such a regulator also could oversee pricing algorithms. In all these contexts, firms (and governmental agencies, in some cases) would submit their algorithms to the regulator for review.[300] This regulatory agency potentially would face the massive task of evaluating all algorithms in use across the private and public sectors. In this context, reviewing pricing algorithms to determine if they are relying on competitors' prices would seem a relatively simple task, compared, for instance, to evaluating whether an algorithm produces biased results, especially if that bias is unintentional.[301] Nonetheless, as algorithmic pricing spreads across markets, as it is likely to do, reviewing all pricing algorithms will be a significant lift. Further, firms will still be incentivized to evade this regulation, because relying on their rivals' prices will allow them to charge prices above the competitive level. This threat will add policing and enforcement to the regulator's plate.

3. Selecting a Regulatory Approach

Deciding which regulatory intervention makes the most sense to address the problems that non-collusive algorithmic pricing presents is not an easy task. The interventions we discuss in this Part—restricting pricing frequency and prohibiting algorithms from incorporating rivals' prices—present clear tradeoffs. Regulations on pricing frequency limit firms' ability to react quickly to shifting market conditions but allow them to rely on the

298. *See, e.g.*, Andrew Tutt, *An FDA for Algorithms*, 69 ADMIN. L. REV. 83, 115 (2017) ("The case for regulation by a single expert agency outweighs the case for regulation by the states or jurisdiction distributed across multiple agencies because algorithms have qualities that make centralized federal regulation uniquely appealing.").

299. *See, e.g.*, Anupam Chander, *The Racist Algorithm?*, 115 MICH L. REV. 1023, 1039 (2017) (arguing that "the problem of algorithmic discrimination is likely to lie . . . in the ways that algorithms might replicate real-world discrimination through their statistical methodologies"); Ngozi Okidegbe, *The Democratizing Potential of Algorithms?*, 53 CONN. L. REV. 739, 744 (2022) (explaining that current "pretrial algorithms . . . maintain existing racial disparities in the pretrial system due to their utilization of inputs that are racially disparate, carceral, and fail to account for the individual and communal harms that pretrial incarceration enacts.").

300. See Tutt, *supra* note 298, at 122 ("Rather than wait for an algorithm to harm many people, we might take the FDA's history as a lesson and instead develop an agency now with the capacity to ensure that algorithms are safe and effective for their intended use before they are released.").

301. *See* Jason R. Bent, *Is Algorithmic Affirmative Action Legal?*, 108 GEO. L.J. 803, 806 (2020) ("The basic problem of unintentional algorithmic discrimination is by now well-recognized.").

full menu of data inputs, including rivals' prices, when setting price. This type of regulation is probably the easier of the two approaches to implement and administer. These regulations would be difficult to evade and do not require an agency to carefully study individual algorithms. Prohibiting algorithms from relying on rivals' pricing places no limits on firms' ability to react nimbly to market conditions (other than changes in their competitors' prices). Firms would be able to adjust their prices whenever they see fit. But pricing without reference to competitors' prices could raise prices in some cases. And implementing this type of regulation will be expensive and greatly expand the role of government. The proliferation of algorithms across society may make such a regulatory expansion inevitable, but it is an added cost to consider when comparing solutions to the algorithmic pricing problem.

Based on what we know currently about algorithmic pricing, a regulatory scheme that limits when firms price, rather than one that restricts how they price, is appealing for typical markets. We believe that this approach would be equally effective but less expensive and less intrusive than one that directly regulates firms' algorithms. Further, there are already real-world models demonstrating that regulating pricing frequency is an administrable reform that can help consumers. That being said, widespread use of pricing algorithms is a relatively new phenomenon. Any definitive conclusions about whether and how to regulate markets where pricing algorithms are harming consumers may have to wait until society gains additional experience with these technologies and until further empirical evidence on their impact emerges.

We recognize that regulation is not the only possible response to higher prices brought about by pricing algorithms; market-based strategies are also available. In the absence of regulation, consumers may change their behavior in response to algorithmic extraction. For example, consumers may adopt algorithmic tools to detect lower prices or increase their use of price comparison websites. These strategies may provide an avenue to mitigate some of algorithms' price effects, to the extent that they reduce search costs and make consumers more likely to choose websites offering the lowest prices. While consumers cannot counter the effects of algorithms directly, they can invest in tools that make them more price responsive. However, even if these tools become more prevalent, the potential effects of algorithms that remain may make regulation an appealing policy solution.

4. Innovation Effects

In addition to their other strengths and weaknesses, both regulatory approaches to algorithmic pricing share the risk of dulling innovation

incentives for pricing technologies. Restricting pricing frequency reduces the incentive to create faster algorithms, while barring algorithms from considering rivals' prices softens incentives to develop more sophisticated price competition strategies.[302] Competition policy typically aims to enhance innovation, not dull it.[303] However, we contend that pricing algorithms are an exception to this general rule. They represent a form of "extractive innovation"—a technological advance that harms rather than helps consumers by transferring wealth from consumers to firms—that competition policy should not encourage.

Enhanced innovation is well understood to be a central goal of competition policy.[304] In general, more competitive markets are thought to produce more innovation, while restraints on competition are viewed as likely to reduce innovation.[305] Not surprisingly, courts, enforcers, and antitrust scholars remain focused on identifying conduct that might threaten innovation.[306]

This goal of promoting innovation does not exist in a vacuum, however. Innovation is considered valuable because it is thought to benefit consumers.[307] Contemporary competition policy and antitrust theory is centered on the concept of consumer welfare.[308] But what if the innovation in question *reduces* consumer welfare? As Tim Wu has noted, antitrust

302. *See supra* Section III.C.4.

303. *See, e.g.*, Makan Delrahim, Assistant Att'y Gen., U.S. Dep't of Just., Antitrust Div., "Video Killed the Radio Star": Promoting a Culture of Innovation (Oct. 8, 2020), https://www.justice.gov/opa/speech/assistant-attorney-general-makan-delrahim-delivers-remarks-47th-annual-conference [https://perma.cc/Y68R-SFZ7] (stating that the Antitrust Division of the U.S. Department of Justice "is committed to ensuring that competition policy remains a force for good in fostering innovation").

304. *Id.*

305. *See, e.g.*, U.S. DEP'T OF JUST. & FED. TRADE COMM'N, HORIZONTAL MERGER GUIDELINES 23 (Aug. 19, 2010), https://www.ftc.gov/sites/default/files/attachments/merger-review/100819hmg.pdf [https://perma.cc/6USH-LJ7Z] ("Competition often spurs firms to innovate."); Giulio Federico, Fiona Scott Morton & Carl Shapiro, *Antitrust and Innovation: Welcoming and Protecting Disruption*, *in* 20 INNOVATION POL'Y & ECON. 125, 125 (Josh Lerner & Scott Stern eds., 2020) ("[C]ompetition promotes innovation" as "[e]ffective rivalry spurs firms to introduce new and innovative products," and exclusionary conduct by a dominant firm "suppresses innovation by foreclosing disruptive rivals and by reducing the pressure to innovate on the incumbent.").

306. *See, e.g.*, United States. v. Microsoft Corp., 147 F.3d 935, 948 (D.C. Cir. 1998) ("[A]ny dampening of technological innovation would be at cross-purposes with antitrust law."); C. Scott Hemphill & Tim Wu, *Nascent Competitors*, 168 U. PA. L. REV. 1879, 1881 (2020) (outlining "a program of antitrust enforcement to protect . . . prospective innovation by . . . future direct competitor[s]" of firms possessing market power).

307. *See* Federico et al., *supra* note 305, at 125–26 ("Competition policy seeks to protect and promote a vigorous competitive process by which new ideas are transformed into realized consumer benefits.").

308. *See, e.g.*, Brooke Grp. Ltd. v. Brown & Williamson Tobacco Corp., 509 U.S. 209, 221 (1993) (noting "the antitrust laws' traditional concern for consumer welfare and price competition"); Jacobs v. Tempur-Pedic Int'l., Inc., 626 F.3d 1327, 1339 (11th Cir. 2010) ("[C]onsumer welfare, understood in the sense of allocative efficiency, is the animating concern of the Sherman Act.").

scholarship suffers from "a serious failure to explain what kind of innovation antitrust should try to encourage" and that generally "the concept" has been "left vague."[309] Wu was referring to the distinction between large-scale industrial innovation and "small-firm, decentralized innovation," but the point applies more broadly, too.[310] The Horizontal Merger Guidelines and other antitrust agency guidance tend to refer generally to innovation as an unalloyed good to be encouraged.[311] Pricing algorithms' impact on consumer welfare raises serious questions about this undifferentiated approach.

The closest antitrust law has come to addressing the possibility of harmful innovation is in cases involving claims of predatory product design. In these types of disputes, plaintiffs are often third-party producers of products that interconnect with a monopoly product.[312] If the monopolist changes its offering such that third-party interconnection becomes more difficult, more expensive, or simply impossible, those producers might claim that the monopolist harmed competition by unlawfully excluding its competitors.[313] The key issue in these product design cases is whether the product change at the heart of the dispute could be characterized as a genuine innovation. Courts generally have found no antitrust problem if the defendant's changes to the relevant product represent an "improvement."[314] Put another way, there is only an antitrust issue with a product design change if it involves no innovation.

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309. Tim Wu, *Taking Innovation Seriously: Antitrust Enforcement if Innovation Mattered Most*, 78 ANTITRUST L.J. 313, 315 (2012).

310. *Id.* at 315–16.

311. *See, e.g.*, U.S. DEP'T OF JUST. & FED. TRADE COMM'N, *supra* note 305, at 23 ("Competition often spurs firms to innovate. The Agencies may consider whether a merger is likely to diminish innovation competition by encouraging the merged firm to curtail its innovative efforts below the level that would prevail in the absence of the merger."); Makan Delrahim, Assistant Att'y Gen., U.S. Dep't of Just., Antitrust Div., Never Break the Chain: Pursuing Antifragility in Antitrust Enforcement (Aug. 27, 2020), https://www.justice.gov/opa/speech/assistant-attorney-general-makan-delrahim-delivers-remarks-thirteenth-annual-conference [https://perma.cc/LDE8-3VCA] ("[W]e aim to ensure that antitrust law protects competition without standing as an impediment to rapid innovation."); *see also Microsoft Corp.*, 147 F.3d at 948 ("[A]ny dampening of technological innovation would be at cross-purposes with antitrust law.").

312. *See, e.g.*, *In re* IBM Peripheral EDP Devices Antitrust Litig., 481 F. Supp. 965 (N.D. Cal. 1979), *aff'd sub nom.* Transamerica Comput. Co. v. IBM Corp., 698 F.2d 1377 (9th Cir. 1983) (involving an allegation that IBM altered its central processing units' interfaces to make them incompatible with peripheral tape and disk drives produced by third-party manufacturers).

313. *See id.* at 1002–03 ("Had IBM responded to the [peripheral manufacturers'] inroads on its assumed monopoly by changing the System/360 interfaces with such frequency that [the peripheral manufacturers] would have been unable to attach and unable to economically adapt their peripherals to the ever-changing interface designs, and, if those interface changes had no purpose and effect other than the preclusion of . . . competition, this Court would not hesitate to find that such conduct was predatory.").

314. *See id.* at 1004 (holding that plaintiff "will not be heard to complain that it was somehow injured by an improved product").

Under this "improvement" standard, the advances in pricing algorithms discussed above undoubtedly qualify as innovation. Pricing algorithms are becoming faster and able to incorporate increasing amounts of data.[315] These are certainly improvements for direct consumers of the algorithms, whether these consumers are in-house or purchase an algorithm on the open market. Further, in most cases, firms do not use improvements in pricing algorithms to exclude competitors in the antitrust sense.[316] They might rely on the algorithm to beat their rivals' prices, but as long as those prices are not predatory, this is not an antitrust violation. Winning market share through a superior pricing algorithm, even when that innovation harms consumers of the products the algorithm prices, has no antitrust remedy under current law.

Antitrust therefore has no doctrinal answer for what to do about innovations that, while genuine improvements, harm consumer welfare. It is also worth highlighting that the consumers harmed in this scenario are not direct purchasers of pricing algorithms. Firms that employ pricing algorithms, as well as their rivals, benefit from advances in algorithmic technology. Innovation in pricing algorithms, when spread unequally among firms, creates the asymmetries that facilitate supracompetitive pricing even in competitive markets.[317] The harm to retail consumers is a result of the advantages pricing algorithms confer on retailers.

While antitrust may not be best equipped to address issues raised by innovations that harm consumers, regulators have more experience reining in harmful innovations and are better positioned to do so. It is not uncommon for firms that produce dangerous products to improve them (i.e., innovate) so that they become more effective and therefore more dangerous. Certain genuine improvements to tobacco consumption devices, guns, and even cars, for example, make these products more harmful for consumers and the broader public, sometimes prompting regulators to ban or limit the effects of these improvements despite their innovative character.[318]

Consider, for example, flavored e-cigarettes. E-cigarettes are devices that allow individuals to ingest nicotine and other chemicals without smoking tobacco. According to the Centers for Disease Control and

315. *See* Zhou, *supra* note 37 ("As algorithms become more powerful and more data becomes available, companies' product and service prices can automatically respond to demand and competition in real time.").

316. *See supra* Section III.A. *But see* Leslie, *supra* note 204.

317. *See supra* Section II.B.

318. *See, e.g.*, James Niels Rosenquist, Fiona M. Scott Morton & Samuel N. Weinstein, *Addictive Technology and its Implications for Antitrust Enforcement*, 100 N.C. L. REV. 431, 455, 467 (2022) ("A reason for regulation of risky products could be that the preferences of some consumers are dangerous or unacceptable for society as a whole, either as a moral matter or because of those preferences' externalities on others.").

Prevention (CDC), e-cigarettes might have positive health benefits for adult smokers if they use them to replace traditional cigarettes.[319] But the CDC asserts that e-cigarettes are "not safe for youth, young adults, and pregnant women."[320] For "kids, teens, and young adults," e-cigarettes are unsafe because "[n]icotine is highly addictive and can harm adolescent brain development."[321] Flavored e-cigarettes provide the same chemical mix as any other e-cigarette, but include an appealing taste, like fruit or mint. From the point of view of the e-cigarette user, a flavored e-cigarette is an improvement over non-flavored e-cigarettes. Based on antitrust case law and most non-legal definitions, the flavored e-cigarette is an innovation.[322] But the science concerning youth smoking shows that it is a harmful innovation. Flavored e-cigarettes increase the likelihood that young people will use these devices, creating serious health risks.[323] Recognizing the danger that flavored e-cigarettes pose, the FDA stated in April 2020 that it would "prioritize enforcement against [a]ny flavored" e-cigarettes "that do not have premarket authorization."[324]

More powerful automobile engines are another example of potentially harmful innovation. Car manufacturers, especially the luxury brands, compete in part on the power of their vehicles' engines.[325] Engine torque and top speed are selling points for some car buyers.[326] Competition to increase zero-to-sixty speeds and top speeds routinely produces product

319. *Electronic Cigarettes*, CTRS. FOR DISEASE CONTROL & PREVENTION, https://www.cdc.gov/tobacco/basic_information/e-cigarettes/index.htm [https://perma.cc/FNS9-LVCR] (July 12, 2021).

320. *Id.*

321. *Quick Facts on the Risks of E-cigarettes for Kids, Teens, and Young Adults*, CTRS. FOR DISEASE CONTROL & PREVENTION, https://www.cdc.gov/tobacco/basic_information/e-cigarettes/Quick-Facts-on-the-Risks-of-E-cigarettes-for-Kids-Teens-and-Young-Adults.html [https://perma.cc/L85RGYSU] (last visited July 21, 2022).

322. *See, e.g.*, *In re* IBM Peripheral EDP Devices Antitrust Litig., 481 F. Supp. 965, 1004 (N.D. Cal. 1979), *aff'd sub nom.* Transamerica Comput. Co. v. IBM Corp., 698 F.2d 1377 (9th Cir. 1983) (rejecting antitrust claim based on "injur[y] by an improved product"). Merriam-Webster describes an "innovation" as "a new idea, method, or device" and explains that "[i]nnovation . . . can refer to something new or to a change made to an existing product, idea, or field." *Innovation*, MERRIAM-WEBSTER, https://www.merriam-webster.com/dictionary/innovation#synonyms [https://perma.cc/UM32-3KKM] (last visited July 21, 2022).

323. *See* Bridget K. Ambrose et al., *Flavored Tobacco Product Use Among US Youth Aged 12-17 Years*, *2013-2014*, 314 J. AM. MED. ASS'N. 1871, 1871–72 (2015) (surveying flavored tobacco use among U.S. youth and finding that "[t]he majority of youth" who had ever used tobacco products "reported that the first product they had used was flavored, including . . . 81.0% of ever e-cigarette users").

324. *See* U.S. FOOD & DRUG ADMIN., CTR. FOR TOBACCO PRODS., ENFORCEMENT PRIORITIES FOR ELECTRONIC NICOTINE DELIVERY SYSTEMS (ENDS) AND OTHER DEEMED PRODUCTS ON THE MARKET WITHOUT PREMARKET AUTHORIZATION (REVISED) 2–3 (Apr. 2020).

325. Nick Kurczewski, *The Quickest Cars of 2022*, U.S NEWS & WORLD REP. (May 3, 2022), https://cars.usnews.com/cars-trucks/fastest-cars-in-the-world (ranking cars on time to go from zero to sixty miles per hour, and observing that "the fastest cars of 2022 deliver something for every fan of high performance driving").

326. *Id.*

improvements and certainly represents innovation. Speeding is widely considered to lead to increased traffic deaths, however.[327] Cars that can go faster are more dangerous, all things being equal. The obvious regulatory reaction in most jurisdictions around the world is to impose speed limits. Capping maximum speed is a response to the harmful innovation of faster cars.[328] Speed limits likely de-incentivize innovation in car engines, at least as far as top speed is concerned.[329] But their safety benefits are significant, so society accepts the tradeoff.

Innovation in pricing algorithms does not risk direct physical harm, unlike e-cigarettes and speeding cars. The harm pricing algorithms cause—higher prices for consumers—is distinct from many other types of innovation harms. It is a rare example of innovation making products more expensive, rather than cheaper, without improving product quality. But the examples of dangerous products show that one way to mitigate these harms is through regulation, even if that means blunting innovation incentives. To be sure, not all innovations that raise prices for consumers should necessarily be discouraged. For example, pricing algorithms may help a less-sophisticated firm recognize that it was (erroneously) pricing below the competitive level, forgoing profits unnecessarily. Thus, algorithms may raise prices by improving the information available to firms. Pricing algorithms also may allow for personalized pricing that charges individuals different prices based on their willingness to pay. This strategy could raise prices to some consumers, but it could also make the product available to more consumers at lower prices. This is a more difficult case for regulation, even though such price discrimination will shift surplus from consumers to sellers in many cases.[330]

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327. *See, e.g.*, NAT'L TRANSP. SAFETY BD., REDUCING SPEEDING-RELATED CRASHES INVOLVING PASSENGER VEHICLES ix (2017), https://www.ntsb.gov/safety/safety-studies/documents/ss1701.pdf [https://perma.cc/LB72-EBLK] ("Speeding—exceeding a speed limit or driving too fast for conditions—is one of the most common factors in motor vehicle crashes in the United States."); Paul A. Eisenstein, *Your Next Car May Not Allow You to Speed on the Highway*, NBC NEWS (Apr. 9, 2019, 2:33 PM), https://www.nbcnews.com/business/autos/your-next-car-may-not-allow-you-speed-highway-n992606 [https://perma.cc/A8UN-YTJF] ("[A]ccording to U.S. safety regulators, excess speed plays a role in about 26 percent of all highway fatalities.").

328. *See* FED. HIGHWAY ADMIN. & INST. TRANSP. ENG'RS, METHODS AND PRACTICES FOR SETTING SPEED LIMITS: AN INFORMATIONAL REPORT 1 (2012), https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa12004/[https://perma.cc/KC3X-52Z8] ("One of the most frequently used methods of managing travel speeds is the posted speed limit.").

329. Other forms of innovation in car engines are not discouraged, such as increases in gas mileage. And the reduction in innovation incentives to create faster engines applies only to cars purchased by retail consumers. Innovation incentives to achieve higher top speeds remain in place for race cars, for example, a market where society is less concerned about consumer harm.

330. *See, e.g.*, David J. Gifford & Robert T. Kudrle, *The Law and Economics of Price Discrimination in Modern Economies: Time for Reconciliation?*, 43 U.C. DAVIS L. REV. 1235, 1241 (2010)

The effects of pricing algorithms show that the character of specific innovations should matter to policy makers. Where innovations harm consumers or the broader public, policy makers, regulators, enforcers, and courts should be less concerned about policies that might reduce related innovation incentives. Indeed, we propose that there is a category of innovation that reduces welfare, generates consumer harm, and deserves close scrutiny by regulators and antitrust enforcers. Dangerous products are an obvious example, but advances in pricing algorithms may also represent an extractive innovation that should be reined in by regulation. In general, more nuance is required in discussions of innovation policy. Just because a product is improved does not mean it enhances consumer welfare or societal well-being.

CONCLUSION

Algorithmic pricing is spreading quickly throughout the economy. Chances are high that most consumers already are buying algorithmically priced products on a regular basis, especially when they make e-commerce purchases. Pricing algorithms offer powerful advantages to sellers, which means their adoption will only grow in the near future, perhaps even extending to brick-and-mortar stores. Academics, policy makers, and antitrust enforcers quickly realized the potential for pricing algorithms to facilitate both explicit and tacit collusion. And these groups also recognized that while antitrust is a useful tool for addressing explicit algorithmic price-fixing conspiracies, tacit collusion is likely beyond the reach of the antitrust laws as currently enforced.

We identify a more fundamental challenge posed by algorithmic pricing: in many markets it will raise prices for consumers even in the absence of collusion. The result could be a massive redistribution of wealth from buyers to sellers. Because the mechanism we describe by which algorithmic pricing raises prices does not involve collusion, antitrust—even broadly defined—cannot reach this conduct. As a result, regulation may be the best solution for protecting consumers in affected markets.

This Article explored the historical precedent for a regulatory response to advances in pricing technologies and strategies. It also proposed two potentially effective regulatory approaches to non-collusive supracompetitive algorithmic pricing: restricting *when* firms price, to eliminate asymmetric pricing frequency, and *how* they price, to bar firms from incorporating rivals' prices in their algorithms. Both approaches are

("First-degree price discrimination involves charging every customer the maximum amount they are willing to pay for each unit of the product sold. This removes all 'consumer surplus' . . . .").

designed to limit the ability of a firm with a superior algorithm to soften competition through reactive price cuts. They each have relative benefits and risks. We propose that the less intrusive reform—restricting when firms can change prices—might be the preferable approach based on our current knowledge of algorithmic pricing. But the technology will continue to develop in unpredictable ways, and we argue that regulators must remain nimble as the landscape changes.