nossos ecrãs, brilhantes e implacáveis, são como uma fogueira à volta da qual nos reunimos (quase como mosquitos), mas, em vez de nos aquecerem, deixam-nos frios e isolados (mas, ao menos, em conjunto)[34].

E talvez, nesta proliferação caótica de *eus* digitais, a nossa procura de unidade tenha sempre sido mal orientada. Talvez nunca tenhamos sido feitos para sermos um só, mas sim para sermos muitos, peças dispersas de um *puzzle* complexo (πολύπλοκος ou χαλεπός) que não se encaixa perfeitamente. *In fine*, a tecnologia, tal como a humanidade, pode estar para sempre (*in aevum*) fraturada. Pode servir não como uma cura para a nossa fragmentação existencial, mas como um instrumento da nossa evolução para abraçar a dissonância como a única verdade que possuímos. Tal como as fendas são por onde a luz entra, os nossos *eus* digitais fragmentados são onde vislumbramos pedaços da unidade que desejamos, mesmo quando nos afastamos dela. Nesses reflexos, podemos encontrar não a totalidade que procurávamos, mas a estranha e caleidoscópica beleza do nosso *Eu* fraturado - o único espelho verdadeiro que alguma vez conhecemos.

[34] "As redes sociais uniram as pessoas, isso é fato. Contudo, não como uma autoestrada larga, pavimentada e sinalizada, que possibilita fácil acesso e evita desvios indesejados. Ela ligou pessoas como um labirinto. Todos estão lá e sabem que os outros também estão. Dividir as aventuras e os riscos do labirinto produz uma curiosa sensação de comunidade e cumplicidade, mas de fato, ninguém se encontra. Os acessos nem sempre são abertos para se achar, alguns são abertos para se perder. A existência compartilhada na imprecisão do labirinto funciona como uma cola poderosa. É a 'solidão interativa' na qual mesmo rodeado de tantos contatos e curtidas, cada um sente-se sozinho. A comunhão das selfies, a amizade das curtidas, a cumplicidade dos compartilhamentos, mostram-se arremedos precários para a necessidade visceral de relacionamento que regula a vida humana. Todo frisson obtido e compartilhado nas redes sociais não tem o objetivo ou mesmo a possibilidade de saciar. À semelhança do sedento, que procura aplacar a sede com água salgada, cada novo gole ampliará ainda mais a necessidade do próximo", Bandeira, Nehemias; Ronchi, Carlos César (2019). *Redes Sociais: A Doce Tirania das Vidas Expostas: Ensaios sobre a Transformação do Viver e Sobreviver na Era das Redes*. Juruá, p. 26.

COOPERATIVE EQUILIBRIUM STABILITY UNDER ALGORITHMIC COLLUSION

Sofia Pires[35]

Abstract: This paper provides a discussion on the possibility of pricing algorithms used in digital markets being a tool capable of overcoming traditional limitations to sustaining tacit collusion. In fact, a critical analysis of the literature may suggest that the automatized monitoring of competitors and the reduced need for communication under algorithmic collusion can increase incentives to keep cooperative equilibria, both by reducing expected gains from deviation and the chances of detection. Further research is needed to assess the true risk of sustained algorithmic collusion, but this idea already consists in an alert to competition authorities to adapt their action to new harms to competition and consumer's welfare that may come with technological progress.

Keywords: algorithmic collusion, artificial intelligence, industrial organizations.

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The idea that the recent technological breakthroughs in IT and AI technologies, with the use of algorithms in digital markets can bring many advantages to both firms and consumers is nothing new. As algorithms with predictive abilities can estimate future variables for variables that are key to firms' decisions such as demand, prices, and competitors' behaviour, they are playing a role in optimising firms decision-making and planning processes[36]. Additionally, they can be applied to optimise firm's resource allocation, reducing production costs[37], which may reduce prices for consumers[38]. On the consumers side, searching and monitoring algorithms[39] can serve as a decision tool that improves consumption decisions[40].

[36] OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, p. 11.
[37] OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, pp. 11, 14-15.
[38] OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, p. 15.
[39] Used to track prices, quality indicators or other products' characteristics relevant to consumers' choice
[40] Gal, Michal; Elkin-Koren, Niva (2017). *Algorithmic Consumers. In* Harvard Journal of Law & Technology, vol. 30, n.º 2, pp. 2-4.

Nevertheless, the application of algorithms in economic activities also raise hard challenges regarding market efficiency and consumer's welfare[41]. This essay will explore the additional difficulties the use of algorithms poses regarding tacit and explicit collusion stability, and the consequent implications for social welfare in digital markets.

Under price competition in traditional markets, tacit collusion happens when the rational price choice for firms is to set prices at the level of what a monopolist would (equation 1). Then, firms can maximize profits by sharing monopoly profits (equation 2).

(1)
$$p^{\text{cooperative}} = p^{\text{monopoly}}$$

(2)
$$\pi^{\text{cooperative}} = \frac{\pi^{\text{monopoly}}}{n}$$

If detected that other firm is setting a price lower than (1) to get all the demand for itself and thus having higher profits, in the next

[41] Namely concerns regarding data privacy and the impact of personalized pricing and algorithmic collusion on consumer surplus.

period, the others will choose the competitive price, and profits will be reduced (*trigger strategy*).

In this case, collusive equilibria are very hard to sustain in large markets[42]. This happens for mainly two reasons: firstly, as a market with many firms is more dynamic, it's harder for parties to converge to the same decisions in order to reach a cooperative equilibrium without communication; furthermore, as shown in (2) as the number of firms (n) in the market increases, the lower the cooperative profits will be[43], which reduces the incentives for sustaining the cooperative strategy in the long-run, increasing the incentives to deviate from it in the short-run[44]. Thus, concerns with tacit collusion risks where only directed to markets with few players and with typically high barriers to entry.

Furthermore, regarding explicit collusion[45], competition authorities have created leniency programmes to incentivize collusive agreements parties to deliver evidence of communication among the involved. The higher is the reward one can get from reporting compared to the expected fine, the more effective is the programme to deter collusion[46].

However, the possibility of algorithmic collusion is likely to dramatically shift this paradigm[47]. Pricing algorithms can be coded in ways that, intentionally or not, can lead to collusive market outcomes. That can happen when firms buy the same algorithm provided by the same IT firm (*hub-and spoke* algorithmic

42 Bellelamme, Paul; Peitz, martin (2010). *Industrial Organization Markets and Strategies.* (1st edition). Cambridge University Press, p. 347.

43 OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, pp. 20-21.

44 Ivaldi, Marc; Jullien, Bruno; Rey, Patrick; Seabright, Paul; Tirole, Jean (2007). *The Economics of Tacit Collusion: Implications for Merger Control.* In "The Political Economy of Antitrust", ed. Ghosal, Stennek, Elsevier, p. 220.

45 Collusion strategy that is coordenated with direct communications among parties.

46 Bellelamme, Paul; Peitz, martin (2010). *Industrial Organization Markets and Strategies.* (1st edition). Cambridge University Press, p. 369.

47 Ezrachi, Ariel; Stucke, Maurice (2020). *Sustainable and Unchallenged Algorithmic Tacit Collusion*. *In* Northwestern Journal of Technology and Intelectual Property, vol. 217, p. 6.

collusion)[48]; when algorithms monitor competitors pricing decisions and choose a price above the competitive level[49] if firms do the same, deviates to the competitive price otherwise (*monitoring* algorithms)[50] or follow a leader that is entrusted of implementing an algorithm as described (*tit--for-tat* algorithms)[51]; when it is programmed to emit and collect pricing signals until they match (*signalling* algorithms)[52]; or in the case of *self-learning*[53] algorithms, where the stage between data collecting and the final pricing decision output works as a blackbox, so the decision process is unknown.

Despite the many existent variations of pricing algorithms, what they have in common is that they weaken traditional collusive equilibria limitations. Firstly, the automatized process of monitoring competitors' pricing decisions and instantaneously react to it[54] under algorithmic collusion eliminates the challenge of finding a focal point and coordinating strategies in large markets. Therefore, cooperative equilibria may tend to become more common in larger (digital) markets than before[55]. Furthermore, firms know algorithms instantly detect pricing decisions that deviate from the cooperative one and will readily provide price war decisions if that's the case. Because the trigger strategy is implemen-

48 OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, p. 28.

49 Calvano, Emilio; Calzolari, Giacomo; Denicolò, Vincenzo; Pastorello, Sergio (2019). *Artificial Intelligence, Algorithmic Pricing And Collusion. In* American Economic Review, vol. 110, n.º 10, p. 3.

50 OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, pp. 26-27.

51 OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, pp. 28-29.

52 OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, pp. 29-31.

53 OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, pp. 31-32.

54 Ezrachi, Ariel; Stucke, Maurice (2020). *Sustainable and Unchallenged Algorithmic Tacit Collusion*. *In* Northwestern Journal of Technology and Intelectual Property, vol. 217, pp. 9-11, 27.

55 Ezrachi, Ariel; Stucke, Maurice (2020). *Sustainable and Unchallenged Algorithmic Tacit Collusion*. *In* Northwestern Journal of Technology and Intelectual Property, vol. 217, p. 8.

ted automatically, expected profits from deviating are reduced, and so firms have less incentives to deviate from the cooperative equilibrium[56] than in traditional markets when it may not be implemented in the period immediately after deviation. Then, even though these problems of coordination might not be avoidable without communication, they may reduce the need for it[57], and thus the creation of evidence that can be used by competition authorities to convict cases of explicit communication. Therefore, as the risk of conviction is reduced, leniency programmes may lose efficiency in deter collusion.

Another layer of complexity to this issue emerges when we consider the use of blockchain networks to coordinate collusive agreements. The execution of smart contracts[58] in a blockchain network can possibly increase the stability of a collusive agreement even more because the technology will automatically operationalise what is in the agreement (i.e. setting a price above the competitive level), not allowing its terms to change without every party's consent[59], thus making deviation even more difficult. While smart contracts inside a blockchain network increase the agreement transparency, it at the same times increase its opacity to agents outside the network. That happens because information shared inside the network is protected by cryptographic technology, and the parties' identity under pseudonymity[60], which reduces chances of detection and conviction by authorities, and therefore the appeal of leniency. Therefore, these technologies, complementary to the use of pricing algorithms, have the potential to increase the occurrence of both tacit and explicit collusion cases, as it further enhances its stability by easing coordination, and reducing incentives for deviating from the cooperative solution and report the agreement to competition authorities.

Then, even considering algorithmic collusion limitations[61], it seems likely that it will allow for an increase in cooperative equilibria stability by the mechanisms discussed before, allowing this kind of strategies to be viable in markets with characteristics where once they weren't[62]. If algorithmic collusion becomes more common and sophisticated, that may have an impact on the price levels in digital markets, which would hinder consumer's welfare. Even though it might be to early too correctly assess the true risks of algorithmic collusion[63], as this is a rather recent phenomenon, the seemingly increased incentives for engaging in these practices should at least be a call for competitions authority to the need for adapt their human capital and *modus operandi* to the fast technological progress in digital markets.

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[56] OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, p. 27.

[57] OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, p. 25.

[58] Schrepel, Thibault (2023). *Collusion By Blockchain And Smart Contracts. In* Harvard Journal of Law & Technology, vol. 33, n.º 1, p. 142.

[59] Schrepel, Thibault (2023). *Collusion By Blockchain And Smart Contracts. In* Harvard Journal of Law & Technology, vol. 33, n.º 1, p. 125.

[60] Schrepel, Thibault (2023). *Collusion By Blockchain And Smart Contracts. In* Harvard Journal of Law & Technology, vol. 33, n.º 1, p. 150.

[61] Calvano, Emilio; Calzolari, Giacomo; Denicolò, Vincenzo; Pastorello, Sergio (2019). *Artificial Intelligence, Algorithmic Pricing And Collusion. In* American Economic Review, vol. 110, n.º 10, p. 36.

[62] OECD (2017). *Algorithms And Collusion: Competition policy in the digital era*. September, p. 25.

[63] Ezrachi, Ariel; Stucke, Maurice (2020). *Sustainable and Unchallenged Algorithmic Tacit Collusion. In* Northwestern Journal of Technology and Intelectual Property, vol. 217, p. 37.