3. Collusion and Supergames

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Introduction

This survey provides a high-level discussion of the theoretical literature on tacit collusion among oligopolies in infinitely repeated non-cooperative games, also known as *supergames*. Tacit collusion among a finite number of firms is sustained through implicit "threats of punishment", as it sometimes called in the literature, rather than through explicit communication or enforceable contracts.[1] To be clear, "collusion" in this context does not mean an express agreement and the "threat" is not a threat in the usual or antitrust sense of the word - there is no actual spoken or written threat - but rather the simple and rational expectation that an aggressive action by one firm can lead to a competitive response by other firms that the first firm may not like. This would make the original action less appealing to the first firm.

Foundational Literature

Early Models of One-Shot Interactions

The seminal formal models on oligopolistic competition were developed by Cournot (1838) and then – in critique of Cournot – Bertrand (1883). Each model considers a static, simultaneous-move game of perfect information where symmetric firms with constant costs produce a homogeneous product and face a known demand curve. In the Cournot game firms choose production *quantities* while in the Bertrand game they choose *prices*. This qualitative difference causes each model to yield qualitatively different *Nash (1951) equilibrium* (NE) predictions: in the Cournot model, firms charge a higher price, earn higher profits, and produce less in equilibrium than in the Bertrand model, whose NE outcome

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[1] Since tacit collusion has the ability to produce better outcomes for firms than in competitive equilibrium, and since an explicit agreement is essentially an attempt to force an outcome similar to a tacitly collusive outcome, there is an obvious incentive for firms to enter into an explicitly collusive agreement. The obvious disincentive is that explicit collusive agreements are illegal in most countries in most circumstances. A well-known example of a modern-day explicit cartel is OPEC.

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coincides with the perfectly competitive equilibrium outcome where firms earn zero profits.[2] These static models were followed by the sequential Stackelberg (1934) duopoly model, where one firm sets its quantity first and the other follows. The *subgame perfect equilibrium*[3] (SPE) of this model is characterized by the "leader" firm earning higher profits at the expense of the "follower" firm.

Despite the qualitative differences, these outcomes more importantly share the following feature: firms do not maximize joint profits. As Figure 3.1 illustrates, firms could potentially earn higher profits by explicitly *colluding* to charge a higher price or produce less output. This is because firms have an incentive to deviate (e.g. undercutting prices to capture the entire market) and have no ability to respond to deviations *because they only interact once*. Firms that instead repeatedly interact over an indefinite or uncertain time horizon[4] can react to deviations; opening up the possibility of tacit collusion sustained by credible implicit threats rather than explicit communication or enforceable contracts.

[INSERT FIGURE 3.1 AND 3.2 HERE SIDE BY SIDE IF POSSIBLE]

Figure 3.1. Joint Payoffs With and Without Tacit Collusion

Figure 3.2. Gains and Losses when Deviating from Grim-Trigger Strategies

Supergame Models

Long term repeated interaction among firms can be modeled as a *supergame*[5] wherein firms repeatedly play a *stage game* – often the Cournot or Bertrand game, or a variant thereof – over an infinite number of periods and discount time according to a *discount factor* that measures how patient/forward-looking a firm is.[6] Supergames can be equivalently modeled as firms repeatedly playing a stage game until some

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[2] Kreps and Scheinkman (1983) show that – under fairly unrestrictive conditions – if firms first simultaneously commit to production quantities before competing over prices, the Cournot NE outcome necessarily emerges.
[3] Selten (1965).
[4] Collusion often "unravels" in SPE when there is a deterministic, finite time horizon, but it is possible under certain setups (e.g. Kreps, et al. (1982)).
[5] In this article, we employ a slight abuse of terminology: technically, supergames have players play the *exact* same game every period. More generally, in a *dynamic game* the stage game is allowed to change over time. In this article, "supergame" refers to a dynamic game with an infinite or uncertain horizon.
[6] Most models in this literature consider firms that simultaneously choose only prices or only quantities. One exception is van den Berg and Bos (2017) who consider firms that simultaneously set prices and quantities. Other supergames discussed herein consider alternating-move setups (for example, Maskin and Tirole (1988b), Eckert (2003), and Noel (2008)).

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ex ante unknown, random time when the game ends (due to, for example, a technological breakthrough that renders the industry obsolete).

In supergames, firms' *strategies* are complete contingency plans that specify the action (e.g. setting a price or quantity) they will take at each point in time, given each possible history of past events they can observe. This enables firms to tacitly collude and earn supra-competitive profits (meaning supra-static-competitive-game-profits) in SPE through credible threats if firms deviate from their strategies.

This was notably established by Friedman's (1971) "Nash threats Folk Theorem." Specifically, he showed that sufficiently patient firms can sustain supra-competitive profits by using *Nash-reversion grim-trigger* strategies. This has firms choose a "collusive action" (setting quantities that yield firms supra-competitive profits) when no firm has deviated from said strategies, but otherwise always choose a "punishing action" (specifically, the static Cournot NE quantity). As Figure 3.2 illustrates, deviation yields a short-term gain to a firm, but – under this non-forgiving self-enforcement scheme – will result in a long-run discounted loss afterwards. The severity of this cost increases with firms' degree of foresight, which is what allows them to sustain higher profits in SPE. This will often (but not always) be the case in the supergames discussed below. Similarly pervasive – and far more concerning – is the large multiplicity of equilibria: any supra-competitive profit profile – in the cross-hatched region of Figure 3.1 for a duopoly – can be sustained if firms are sufficiently patient. In simpler terms: it's possible that "anything goes," in SPE. This result holds more broadly in supergames; in light of this, *equilibrium refinements* of SPE are often employed to tighten equilibrium predictions.

Folk Theorems and Equilibrium Selection

Supergames are often plagued by a large multiplicity of equilibria and equilibrium payoff profiles. Since Friedman (1971), multifarious folk theorems have been developed for a wide variety of supergames such as those with imperfect public monitoring (Fudenberg, Levine and Maskin, 1994), private monitoring with (Obara, 2009) and without (Sugaya, 2022) communication, unknown payoffs and monitoring structures (Fudenberg and Yamamoto, 2010), and those wherein future stage games are uncertain (Krasikov and Lamba, 2023). Since "anything goes" in SPE for a broad swathe of supergames, it is often useful to focus on refinements of SPE. For example, sequential equilibrium (Kreps and Wilson, 1982)[7] can

[7] See also Jindani (2022) who developed a stochastic learning equilibrium selection rule.

be employed in incomplete information contexts to ensure “sensible” beliefs off the equilibrium path. In imperfect information contexts, perfect public equilibrium (Fudenberg, Levine and Maskin, 1994) is used to focus attention on strategies where agents condition only on the publicly observable history of events, not their own private information.

Another refinement is *Markov Perfect Equilibrium* (MPE), developed by Maskin and Tirole (1988abc, 2001), which restricts attention to strategies where players’ behavior only depends on the value of a payoff-relevant state. This solution concept is often used in dynamic games not only because it may reduce multiplicity of equilibria, but may also yield tractability. In a series of three papers, Maskin and Tirole (1988abc) analyze the MPE of a variety of alternating-move duopoly supergames. Maskin and Tirole (1988a) consider the case of a natural monopoly with large fixed costs; under this setup there exists a *unique* symmetric MPE wherein only one firm produces. The price-competition model of Maskin and Tirole (1988b) has substantial multiplicity of MPE, but the authors notably observed the possibility of *Edgeworth cycles* to emerge.[8] Eckert (2003) and Noel (2008) show that Edgeworth cycles can emerge in more general settings than the one considered in Maskin and Tirole (1988b). Finally, Maskin and Tirole (1988c) analyze the MPE of an alternating-move Cournot supergame and show that under certain conditions it is unique. Interestingly, they find that patience can possibly undo tacit collusion in this setting.

As with any equilibrium refinement, there is always the possibility of inadvertently excluding plausible equilibria that may be of interest. For instance Salz and Vespa (2020) point out that “when the gains from tacit collusion are large, behavior may not be captured by an MPE.” This motivated them to experimentally investigate the restrictiveness of this equilibrium refinement for counterfactual predictions in a dynamic oligopoly context, basing their experimental design on the firm entry/exit supergame from Ericson and Pakes (1995). Despite the valid concern they raise, Salz and Vespa (2020) find that focusing on MPE introduces only “relatively modest bias” to counterfactual predictions.

Focusing on a particular class of punishment protocols may also qualitatively affect the equilibrium outcomes that can emerge. The Nash reversion grim trigger class of strategies considered by Friedman (1971) are only one type of self-policing scheme. If firms are allowed to employ other punishment protocols, an even larger multiplicity of equilibria can be sustained. For example, Fudenberg and Maskin

[8] Edgeworth cycles follow a distinctly asymmetrical pattern characterized by rapid price increases followed by gradual declines.

(1986) showed that under certain conditions any feasible strictly individually rational average payoff profile can be sustained in SPE by sufficiently patient firms.[9]

It has also been suggested that the unforgiving grim trigger strategies may not be plausible if firms are allowed to renegotiate, since it is in firms' best interests to reset tacit collusion. This has prompted the development of *renegotiation-proof* refinements that rule out continuation play that is Pareto-dominated from firms' perspective (Rubinstein, 1980; Bernheim and Ray, 1989; Farrell and Maskin, 1989). A related concept of *contractual equilibrium* was developed by Miller and Watson (2013) who – unlike the aforementioned papers – explicitly model renegotiation.[10] Abreu (1986, 1988) considers asymmetric, optimal, and forgiving forms of punishment. He identifies a simple "stick-and-carrot" punishment protocol that entails only one period of punishment after deviation which can nevertheless be more severe than non-forgiving punishment protocols.

The vast multiplicity of equilibria in supergames is still very much an open problem. As is often the case, there is a symbiotic relationship between theoretical and empirical (especially experimental) economics, and this active area of research is no different. While the discussion herein focused on the theoretical side of this literature, readers are referred to the excellent survey and meta-study by Dal Bó and Fréchette (2018) on the growing experimental literature on the determinants of collusion/cooperation supergames and the cutting-edge experimental work by Boczoń, Vespa, Weidman, and Wilson (2023).

A large part of the collusion supergame literature investigates the factors that impede or facilitate firms' ability to tacitly collude. As mentioned earlier, patience typically enhances firms' ability to collude. Collusion is also typically facilitated by having fewer firms in the market (Selten, 1973; Ivaldi, et al., 2003). The rest of this survey discusses models that investigate various other factors that play a role in tacit collusion.

The Role of Monitoring Ability

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[9] That is, any payoff profile where each firm earns at least their "minmax" payoff (the lowest payoff an optimizing firm can be forced to receive by other firms).

[10] It should be noted however that contractual equilibrium was developed for supergames with transfers and cheap talk communication so that collusion in this particular setting is not completely tacit. See the more recent work in Watson, Miller and Olson (2020).

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The sustainability of tacit collusion depends in part on firms' ability to monitor one another. This consideration was notably stressed by Stigler (1964), who conjectured that tacit collusion can be made considerably more difficult to sustain if firms can secretly cut prices. This paper served as the seed for a large research area studying tacit collusion among firms that can only *imperfectly* monitor each other.

In imperfect *public* monitoring models, firms have noisy, *publicly-observable* information about each other's actions. A seminal model of collusion with imperfect public monitoring was developed by Green and Porter (1984).[11] They analyzed a Cournot supergame with noisy i.i.d. demand shocks where firms *only* observe the price of the good, not the shock or other firms' quantity choices. This limits firms' ability to self-police, since a price decline could be due to a demand shock or due to deviations by other firms. The authors show that collusion can still be sustained in equilibrium if firms use *trigger price strategies*: when prices are sufficiently high, firms jointly produce less than they would in a static Cournot NE, but when the price falls below a certain "trigger price" level, firms engage in temporary "price wars" by reverting to their NE strategies of the static Cournot game for a finite number of periods. Unlike the Nash reversion grim-trigger strategy equilibria in the benchmark Cournot supergame, punishment is observed on the equilibrium path and persists only temporarily. Interestingly, firms engage in this collective self-punishment when the price falls below the trigger level despite knowing that – in equilibrium – price drops are due to shocks, not deviations from collusion.

There exist many other equilibria in the Green and Porter (1984) model (Fudenberg, Levine and Maskin, 1994, p. 1024). For example, Abreu, Pearce and Stacchetti (1986) identify optimal symmetric sequential equilibria in a similar model where firms switch between two production level "regimes" according to a Markov chain.[12] However, Fudenberg, Levine and Maskin (1999) point out that the equilibria considered in both Green and Porter (1984) and Abreu, Pearce and Stacchetti (1986) are inefficient due to their symmetric nature, and show that there exist asymmetric strategy profiles that are "nearly" efficient due to their minmax-threat Folk Theorem (Theorem 6.2).

Another strand of this literature considers imperfect *private* monitoring, where firms only receive privately observed signals. Typically, collusion is more difficult to sustain in such models due to firms

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[11] See also the related work by Porter (1983). Aoyagi and Fréchette (2009) experimentally investigate an analogous *prisoner's dilemma* supergame with noisy public monitoring. Abreu, Pearce and Stacchetti (1990) study imperfect monitoring supergames in a more general setting.
[12] See also Chen (1995) and Yoon (1999) who consider the weakly renegotiation-proof equilibria of the Green and Porter (1984) model.

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having relatively limited, siloed information. Aoyagi, Bhaskar and Fréchette (2019) note that in prisoner's dilemma supergames, "the lack of common knowledge of histories becomes a major obstacle for cooperation." Under certain private monitoring settings, grim trigger strategies can fail to sustain collusion (Compte, 2002). In light of firms' relatively limited information under private monitoring, several papers investigate how collusion can be potentially facilitated via communication; notable examples include Kandori and Matsushima (1998), Compte (1998), Athey and Bagwell (2001, 2008), Harrington and Skrzypacz (2011), Chan and Zhang (2015), Awaya and Krishna (2016, 2020), and Awaya (2021). In contrast, Hörner and Jamison (2007) and Sugaya (2022) focus on cases without communication.

Broadly speaking, the conventional wisdom is that increased monitoring ability typically facilitates collusion.[13] Kandori (1992) shows that this is necessarily the case in imperfect public monitoring settings like in Green and Porter (1984) and Abreu, Pearce and Stacchetti (1986, 1990) because defections can be detected more accurately. Sugaya and Wolitzky (2018a) show that this is also true in Bertrand and Cournot supergames with imperfect private monitoring under certain conditions.

Only relatively recently has it been shown that increased monitoring ability can impede collusion in certain cases. This was notably observed by Sugaya and Wolitzky (2018), who point out that increased information enhances firms' ability to (1) *monitor* one another, (2) adapt *collusive* behavior (and *punishments*) in response to market conditions, and (3) adapt *deviations* to market conditions. The authors show that it is possible for the first two effects to be dominated by the third effect, so that under certain conditions having less information about other firms' behavior actually facilitates collusion. Specifically, they consider a homogenous-good, multimarket price competition supergame with stochastic cost and demand where each firm has a "home market" wherein they have a cost advantage. In this setting, the firms can maximize profits under Harrington's (2006, p. 34) "home-market principle," where firms optimize and operate only in their respective home markets. In their model, firms can detect when another firm has entered their market and can receive signals about the state of price, costs, and demand in other markets. They find that under certain conditions, having less precise signals about competitors facilitates collusion, which is intuitive: in their model, information about other markets does not help firms optimize within their own home markets, and only serves to tempt firms to

[13] Whinston (2006, p. 40), Carlton and Perloff (1995, p. 136), U.S. Department of Justice and Federal Trade Commission (2010, p. 26).

encroach on others' markets.[14] Kloosterman (2015) also finds that more information can impede collusion in Markov games. Miklós-Thal and Tucker (2019) and O'Connor and Wilson (2021) – discussed below – find that reduced demand uncertainty can also adversely affect firms' ability to collude. See Obara and Kim (2023) for a recent analysis of the role of monitoring ability in a relatively general imperfect monitoring setting.

Demand Fluctuations

Rotemberg and Saloner (1986) study an oligopoly supergame where i.i.d. demand shocks are *observable* (in contrast to Green and Porter (1984) and related models discussed in the previous section). They focus on symmetric equilibrium outcomes wherein joint profits are maximized and consider both a price-setting and a quantity-setting setups, but their main focus and clearest-cut results are in the former case. In either case, they find that equilibrium prices can be lower during periods of high demand. This counter-cyclical equilibrium prediction always holds in their analysis of the price-setting case, and is largely driven by higher demand increasing firms' temptation to deviate. This logic and result hold in the quantity-setting case under certain conditions but not in general.[15]

Several follow-up papers investigated the implications of non-i.i.d. demand fluctuations. Haltiwanger and Harrington (1991) consider the case where demand evolves in a deterministic, cyclical manner, similarly focusing on symmetric SPE outcomes wherein joint profits are maximized. They find that prices under such SPE are lower *ceteris paribus* when demand is falling (as opposed to rising). Note however that not all the results in Harrington (1991) hold when firms face capacity constraints, regardless of whether they are exogenous (Fabra, 2006) or endogenous (Knittel and Lepore, 2010). Kandori (1991) considers the case when serially correlated demand shocks follow a Markov process. He finds that in the symmetric SPE that maximizes joint profits, prices are counter-cyclical under certain conditions on the number of firms and their (common) discount factor. Bagwell and Staiger (1997) use a modeling approach motivated by Hamilton (1989) where demand evolves according to a Markov growth process, stochastically alternating between periods of "fast" and "slow" growth. They focus on the evolution of "most-collusive prices," which they define as the highest prices sustainable in a symmetric SPE. Their baseline results depend on whether expected demand growth is positively or negatively correlated with its current growth rate: if they are positively (negatively) correlated, then the most-collusive prices are

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[14] In the sense of Blackwell's (1951) theorem.
[15] For example, when demand and marginal costs are affine functions.

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weakly procyclical (countercyclical), following a cycle whose amplitude decreases (increases) with the expected duration of expansions (recessions). To facilitate comparison with Rotemberg and Saloner (1986), they also consider an extension where demand faces transitory i.i.d. shocks. In this extended model, they find that in both recessions and expansions, higher i.i.d. demand shocks induce weakly lower collusive prices. They also find that their aforementioned result on the pro/countercyclicality of collusive prices is robust to this extension.

Bernhardt and Rastad (2016) extend the analysis of Rotemberg and Saloner (1986) in a different direction, investigating quantity-setting collusion among firms that have fixed costs and are risk averse. They motivate the latter assumption by arguing that "country cartels" (e.g. OPEC) may "not care about profits *per se*, but rather about the utility their citizens derive from the profits" or that "cartel members may inherit the risk aversion of managers." They focus on Nash reversion grim trigger strategies. They observe that as a result of both fixed costs and risk aversion, the short-run gain from defection is "U-shaped" in the level of demand. That is, collusion is easier to sustain (within the aforementioned class of SPE) for intermediate levels of demand.

Firm Asymmetry and Heterogeneity

Many of the models discussed in previous sections consider *symmetric* firms, an assumption that is often appealing due to its tractability. Of course firms are in reality not exactly identical, which may make it more difficult to collude. This is indeed a common finding of many (but not all) papers in this sub-literature.

A conventional wisdom is that cost asymmetries hinder collusion because more efficient firms may have more to gain from deviation and may be more likely to do so as a result (Miklós-Thal 2011, p. 100). This intuition may hold when restricting attention to grim-trigger strategies as in Bae (1987) and Harrington (1991), but holds less strongly when attention is relaxed to a broader class of strategies (Miklós-Thal 2011).

Another strand of this sub-literature investigates the effect of heterogeneous capacity constraints/capital stocks, which is also typically found to hinder collusion. Compte, Jenny and Rey (2002) study a Bertrand supergame where firms have heterogenous capacity constraints and consumers have unit-demand functions, finding that larger firms have the strongest incentives to deviate. In contrast, the smallest firms have the strongest incentives to deviate in Vasconcelos (2005), who study a Cournot supergame where firms have heterogenous capital stocks and face an affine demand function. Bos and Harrington (2010) consider a Bertrand supergame where firms have heterogenous capacity constraints, face a relatively more general demand function, and – most notably – arrival at the tacitly collusive outcome is *endogenous*. Under this setup, it is possible to observe stable tacitly collusive equilibria that are not *all-inclusive* (i.e., not including all firms in the market). In such cases, reallocating capacity among "medium" size firms may have the largest positive effect on the stability of the equilibrium. The dynamic Cournot duopoly model in Fagart (2022) endogenizes firms' capacity constraints, which can be increased through "at least partially" irreversible investments. In this model, the author observes a quite atypical result: within the class of grim trigger strategies the paper focuses on, collusion is feasible in equilibrium only for *intermediate* discount factors. Typically, patience can only facilitate collusion in supergames, but in Fagart (2022) it is possible for firms to be "too patient" to collude. This is because firms can deviate by increasing capacity, which has long-run gains.[16]

Building on results in Harrington (1989) and Andersson (2008), Obara and Zincenko (2017) consider a Bertrand supergame where firms have heterogeneous discount factors, but are otherwise symmetric. Despite the large multiplicity of equilibria the authors are able to derive relatively sharp and complete characterizations of equilibrium behavior. They find that any price above marginal costs can be sustained if the average discount factor exceeds

$$1 - \frac{1}{\text{number of firms}},$$

and otherwise collusion is not possible.[17] That is, the tacitly collusive equilibrium hinges on firms' average degree of patience being above a threshold that becomes increasingly demanding as the number of firms grows. Unlike many other papers mentioned in this section, the authors find that heterogeneity in discount factors does not directly affect firms' the likelihood of collusion. They also characterize properties of collusive equilibria that are Pareto efficient (from firms' perspective). They find under "most" such equilibria, firms always set monopoly prices; otherwise – in equilibria with

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[16] For related work that consider how firms' capacities evolve over time, readers are referred to Benoit and Krishna (1987), Davidson and Deneckere (1990), Feuerstein and Gersbach (2003), Besanko and Doraszelski (2004), and Paha (2017).
[17] A very similar relationship between the number of firms and their (common) discount factor was seen in Kandori (1991), which was discussed in Section 0.

sufficiently asymmetric payoffs – firms initially set prices below the monopoly level, but prices quickly and monotonically converge to the monopoly level. They also observe that – in contrast to the symmetric case – efficient collusive equilibria cannot be stationary since firms with heterogeneous discount factors find it mutually beneficial to transfer market shares to one another over time. However, in the long run they observe that all efficient collusive equilibria must converge to a *unique* stationary equilibrium.

Behavioral Considerations

A relatively recent strand of the theoretical tacit collusion literature has investigated the effect of deviating from the traditional assumptions that agents are fully rational and Bayesian.

Motivated by experimental findings in Engel (2011) and Engelmann and Müller (2011), Santore, Li and Cotten (2015) consider collusion among firms run by managers with *other-regarding preferences*, receiving disutility if they lower consumer surplus. The authors find that other-regarding managers are less collusive in the sense that they set lower prices (relative to the rational case) but also identify a novel channel through which profit-sharing facilitates collusion.[18]

The traditional assumption in economics is that agents *exponentially* discount time so that they have time consistent preferences. Obara and Park (2017) develop a theory of supergames that allows for a more general class of discounting, allowing agents to be present/future biased. Focusing on a symmetric class of SPE, they show that relaxing the exponential discounting assumption has a non-trivial effect on the nature of "worst punishment" equilibria in supergames.

Cusumano et al. (forthcoming) consider two firms that produce a homogenous good and a rationally inattentive consumer with unitary demand. When the consumer has sufficiently high attention costs, they observe that firms earn higher profits under competition than they do under collusion.[19]

Misspecified Learning and Artificial Intelligence

[18]A related work is Hervas-Drane and Shelegia (2022) who analyze the effect of profit- and revenue-sharing on collusion in a model based on Varian (1980).
[19] Related work on imperfect competition with rationally inattentive consumers includes Matějka and McKay (2012), Martin (2017), and Hefti (2018).

In recent years, machine learning (ML) and artificial intelligence (AI) have been receiving increased attention across a variety of fields, and the collusion supergame literature is no exception. Online retailers have been increasingly adopting ML/AI pricing algorithms (White House, 2015) which can conceivably – but not completely obviously – collude. For example, Klein (2021) notes that *Q-Learning* algorithms – a type of reinforcement learning algorithm based on dynamic programming – are "theoretically guaranteed to converge to optimal behavior under mild conditions,'' in single agent environments, but not when "when multiple interacting Q-learning algorithms are learning simultaneously."

The computational results from Calvano et al. (2020) suggest that autonomous pricing agents using Q-learning algorithms will learn to tacitly collude in a price-competition supergame. Klein (2021) also finds that Q-learning algorithms may also learn to collude when competing in the price-competition supergame of Maskin and Tirole (1988b).

In addition to using AI pricing algorithms, AI can also be used to reduce uncertainty about market conditions, such as predicting the state of demand. This consideration is investigated by Miklós-Thal and Tucker (2019) and O'Connor and Wilson (2021), who respectively consider models similar to Rotemberg and Saloner's (1986) and Green and Porter's (1984). Each paper finds that better demand prediction ability does not necessarily facilitate firms' ability to collude.

AI algorithms can also be *misspecified*, opening up the possibility of *mis*learning. This is considered by Hansen et al. (2021) who show that competing pricing algorithms may still collude in the long run under certain conditions, and through a novel mechanism. Specifically, they consider firms using independent multi-armed bandit algorithms that balance "exploration" (learning about a static, initially unknown demand curve) and "exploitation" (setting its perceived profit-maximizing price). Setting prices provides a noisy signal of the demand faced by each firm; the authors assume that firms' algorithms are misspecified in the sense that they neglect the effect of other firms' price-setting decisions. The authors show that when the signal-to-noise ratio of price experiments is sufficiently high, firms' algorithms set supra-competitive prices in the long-run due to an upward bias resulting from their misspecification. Jehiel and Samuelson (2023) also observe collusive incentives that emerge as a result of agents' mispecification.

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In light of the concerns raised by the previous papers discussed in this section, a recent paper by Johnson, Rhodes and Wildenbeest (2023) considers the problem of designing a platform that can counteract algorithmic collusion and increase consumer welfare. They consider two types of policies that steer demand toward firms that cut prices, and their results suggest that these policies are robust to firms' patience.

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