Collusion with Public and Private Ownership and Innovation

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Abstract

We argue that, by enforcing the regular provision of vetted information, public ownership can help firms coordinate strategy to avoid head-to-head competition. Such "collusion" opportunities increase the profitability of existing technologies, but may hurt innovation incentives. We show that collusion opportunities benefit firms that either do not consider innovating attractive or consider innovating very attractive. For moderately attractive innovation opportunities, private ownership dominates. By making it harder to coordinate with rivals, private ownership helps firms overcome time inconsistency problems related to abandoning innovation too easily. The predictions of our model and its extensions shed light on several puzzling stylized facts.

Keywords: public and private ownership, innovation, coordination, collusion.
JEL Classification: G31, G32, L41, O31

1 Introduction

The recent decline in public ownership has been widely trumpeted in academic work (Gao et al., 2013; Doidge et al., 2016). One explanation that stands out is the plethora of regulation, information requirements, and public scrutiny faced by public firms, which not only impose costs, but could also reveal valuable information to competitors (Bhattacharya and Ritter, 1983) and lead firms to neglect long-term strategies, such as investing in innovation (Stein, 1989). However public firms' profits are near record highs, and firms vulnerable to leakage of sensitive information are doing especially well. Indicative is that the ten-year annualized returns of the S&P 500 Biotechnology and Pharma Select Industry Indexes were 17% and 13%, respectively, easily outperforming the market at large.[1] Furthermore, though the evidence on how exactly public ownership affects innovation is mixed (Bernstein, 2015; Acharya and Xu, 2017, Gao et al., 2018), one thing seems clear: With 40% of new patents being produced by public firms, and with these patents being more cited for all of the years spanning 1970-2010 (Kogan et al., 2017), public firms remain serious drivers of innovation. Illustrating that they are often also at the forefront of developing long-shot game-changing technologies, the common belief in technology circles is that "Google is furthest along in quantum technology" and "Microsoft has the most comprehensive plan to make the software required."[2]

In this paper, we analyze why public firms may have an edge at maintaining high profitability and relate this question to why some public firms appear leaders, while others laggards, in innovation. We argue that, by committing firms to the regular provision of transparent and vetted information, public ownership creates collusion opportunities not available under private ownership. While collusion typically refers to legally questionable strategies like fixing prices or quantities,[3] we primarily have in mind legitimate strategies aimed at avoiding competition, as typically prescribed by the strategy literature. For example, to carve out a niche for itself, one car producer may specialize in six cylinder, while another in four cylinder cars; one IT firm may focus on developing the hardware, while another the software required to exploit a new technology. We highlight that a key factor helping firms avoid invading each other's turfs is *mandatory* reporting on things such as cash flows, investments, new products and services, large customers, etc. Voluntary reporting cannot achieve the same effect.

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[1] These statistics are as of May 2018.

[2] The Economist, Technology Quarterly, March 9, 2017.

[3] Illegal collusion is pervasive and spans all industries. Recent cartel cases include Procter and Gamble, Unilever, Bauch & Lomb, Sony, Toshiba, LG, Nvidia, BMW, Daimler, VW, GM, Ford, ExxonMobil, Verizon, AT&T, Visa, Master Card, Metro Goldwyn Mayer, News Corp, UPS, Northwest Airlines.

By affecting the margins on existing services and products, strategies to avoid head-to-head competition have an impact on firms' incentives to innovate. We show that such collusion opportunities lead to a U-shaped relationship between the preference for public ownership and the attractiveness of innovation technologies. Specifically, public ownership is beneficial either when firms face weakly attractive innovation opportunities or very attractive opportunities. In the former case, being able to collude on the old technology creates a valuable exit option if the new technology's development does not go well. Instead, when firms face highly attractive innovation opportunities, public ownership could make these opportunities even more attractive by facilitating potential cooperation with rivals that are also likely to pursue them. For innovations in the middle spectrum, private ownership dominates, as it helps firms commit not to abandon the development of new technologies too quickly, which undermines effort incentives. We use these insights to shed light on the above contradictory evidence as well as on further evidence that we compile.

Our model features two firms, an innovative player ('the innovator') and an incumbent that operate in the same market over two periods. This setting has two main elements. First, in the initial period, the innovator can start exploring a new technology, which requires hiring an R&D team that needs to be motivated to exert unobservable effort. At an interim date in that period, the innovator obtains a signal indicating the new technology's profitability. At that point, exploration can be abandoned and the innovator can adopt the incumbent's technology. However, if the new technology is not abandoned and is successful, the innovator obtains high returns from being a first-mover. The second main element of our model is that, when both firms use the same technology, they might try to engage in tacit collusion. What stands in the way of colluding, however, is that each firm faces a type of a prisoner's dilemma: Coordination over two periods is beneficial, but firms might have incentives to deviate. Such deviations are difficult to detect, since firms do not observe each others' actions and must make noisy inferences about these actions.

Public ownership helps in sustaining collusion, because it commits firms to publicly report their cash flows and other relevant information. Such reporting not only reduces the inference errors about whether firms stick to a conjectured collusive equilibrium, but also gives valuable information about the inferences that others have made. Making information mutually observable is crucial for coordination, as firms can better anticipate each other's actions based on that information. In particular, when it is commonly observed that one of the firm's cash flows are low, both firms know that this should trigger abandoning collusion, which makes it mutually optimal to do so. Having such a trigger is necessary for supporting a collusive equilibrium, as it makes it clear that deviations, which reduce the other firm's cash flows, will result in an unfavorable outcome for all.

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The reason a private firm cannot replicate the same equilibrium is that it cannot commit itself to abandon future collusion when its cash flows are low. With cash flows being private information, the other firm would not know when a trigger strategy of abandoning collusion is about to be played. Thus, when firms are supposed to be in a collusive equilibrium, the other firm would most likely continue to collude, making it suboptimal for the private firm to abandon collusion when its cash flows are low. This ex post incentive not to act on signals pointing at a deviation from collusion invites such deviations and makes it impossible to support a collusive equilibrium.

The option to collude on the existing technology can be beneficial for the firm, as it improves its ex post profitability. However, it also makes it more likely that the innovator abandons the development of the new technology in the face of an interim discouraging signal. This can lead to a time-inconsistency problem under public ownership: abandonment becomes too likely, making it very expensive to motivate the R&D team to exert effort. Thus, public ownership leads to a trade-off between a higher cost of motivating effort and having a better abandonment option.

Which of these two effects dominates depends on the new technology's expected profitability. We show that, if that profitability is relatively low, the innovator is better off under public ownership. In this case, the option to abandon the new technology in case of early difficulties and collude on the existing one is very valuable. Things change if the new technology's expected profitability is sufficiently high. Then, the option to collude on the existing technology associated with public ownership becomes less important compared to the higher cost of motivating the R&D team. Hence, private ownership dominates. Finally, if the new technology's expected profitability is so high that also the incumbent decides to pursue it, public ownership becomes optimal again, as it offers collusion opportunities on the new technology. This leads to a U-shaped relation between the attractiveness of public ownership and the new technology's expected profitability. This difference in preferences for public and private ownership is further reinforced when considering in addition that, for intermediately attractive technologies, a private firm could keep the incumbent in the dark that it is developing that technology and, thus, reduce the likelihood that the incumbent starts pursuing it as well.

We extend the model along several dimensions. First, we analyze the innovator's decision to scale up and grow. By remaining small, an innovator may be able to chip away market share from incumbents without triggering a response. This could create incentives to stay 'below the radar screen' by remaining small and private. It also encourages it to use the incumbent technology and, hence, reduces its innovation incentives. Second, we analyze investing in the competitor's equity as an alternative way to achieve collusion.

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When buying an equity stake in the innovator, the incumbent's own innovation incentives are reduced as it benefits from the innovator's payoffs. Yet the overall effect on innovation is ambiguous, as the innovator's innovation incentives are stronger when not competing with the incumbent on the new technology. Third, we show that achieving collusion through voluntary reporting is hard, as absent exogenous strict reporting requirements, private firms would have ex post incentives to add noise to their reports. In our discussion of the empirical implications of our analysis, we also point to some tentative evidence consistent with the prediction that being public may facilitate the avoidance of competition.

The question when firms prefer public and when private ownership has a long history in the finance literature. Our main contribution is to address this question from a novel angle by building on insights from the game theoretic literature that relate transparency to collusion (Green and Porter, 1984; Bhaskar and Van Damme, 2001). Indeed, the higher transparency in public firms is one of the text-book differences between public and private ownership. However, while the prior literature has highlighted that the sharing of sensitive information could make firms reluctant to go public (Bhattacharya and Ritter, 1983; Maksimovic and Pichler, 2001), we point out that the commitment to sharing such information could make going public attractive for firms in concentrated industries, as it could help them avoid competing with each other. Thus, our paper contributes more broadly to the literature linking corporate finance and industrial organization. Recent related contributions include Matthews (2006), who analyzes the effect of interfirm equity stakes on competition and innovation; Fulghieri and Sevilir (2011) and Phillips and Zhdanov (2013) who analyze the effect of takeovers on innovation; Chod and Lyandres (2010) who argue that the better diversification of investors in public firms gives these firms a strategic advantage in more competitive industries; and Kang and Lowery (2014) and Hatfield et al. (2017) who model collusion among IPO underwriters. We add to these papers by analyzing the interaction of public ownership with collusion and innovation incentives.

In line with our premise that public ownership may help facilitate collusion, the law literature has discussed the concern of regulators that conference calls with stock analysts could act as a means of disclosing unscripted sensitive information to rivals, inviting collusion (Steuer et al., 2011).[4] Related, Bourveau et al. (2017) show that the tightening of antitrust laws prompts firms to disclose more information in their reports. The authors argue that this may help firms shift from explicit cartel agreements to supporting tacit collusion. We add to this literature by asking why private firms cannot replicate a collusive equilibrium by voluntarily disclosing information. We show that the key property of public

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[4]Such concerns also feature in the OECD Competition Committee (2012) roundtable discussions.

ownership is that it commits firms to a high reporting standard, regardless of whether this is in their best interest ex post. Without this commitment, collusion breaks down.

One of the advantages of private ownership in our model is that it helps firms to stay on course, in the sense of a lower likelihood of abandoning innovation after a discouraging signal. Specifically, the inability to commit to a new technology gives rise to time inconsistency problems, which might be exacerbated under public ownership. These insights contrast with Ferreira et al. (2014) who argue that the lack of transparency associated with private financing makes it hard for outsiders to distinguish whether a private investor exits due to an illiquidity shock or because the firm's innovation has failed. Somewhat reminiscent of Grossman and Stiglitz's (1980) information efficiency paradox, this makes it less costly for private investors to exit, making them ex ante more willing to invest in innovation. Contrary to our analysis, there are no time inconsistency problems in Ferreira et al. (2014). Exit is desirable. In contrast, we emphasize the importance of endurance and commitment. Another key difference is that private ownership in their paper always dominates when exploring new ideas. Instead, we predict a U-shaped relationship between the attractiveness of innovation and that of private ownership.[5] Furthermore, we discuss how the relative sizes of the firms involved and the acquisition of equity stakes relate to the choice of public ownership. These different perspectives generate an interesting contrast in empirical predictions.

The U-shaped relationship between the attractiveness of innovation and public ownership is also the main difference to the managerial myopia literature in which a manager's focus on the current stock price can also lead to time inconsistency (Stein, 1989). The difference is that the reason for time inconsistency in our model is that the firm undermines ex ante innovation incentives when it can fluently respond to interim signals on the new technology. This becomes particularly acute when it can collude on the existing technology and, thus, faces an attractive exit option. Another difference is that time inconsistency becomes less important when several firms try to develop a new technology, as then coordinating not to compete on that technology becomes important.

Our analysis relates also to more than fifty years of industrial organization literature analyzing the effect of market concentration on innovation.[6] The novel aspect of our

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[5]The cheaper access to capital can help the firm invest in more innovation, especially if the firm reaches investors who have more aligned beliefs with those of the firms' managers (Allen and Gale, 1999). The empirical evidence is supportive of such theories. Acharya and Xu (2017) find that public firms in external finance dependent industries spend more on innovation and have a better innovation profile than private firms, while the same is not true for internal finance dependent industries. We depart from this discussion, as financial constraints do not feature in our model.

[6]The question whether competition is good for innovation goes at least back to Schumpeter (1934, 1942). Key factors are whether innovation would have a similar advantage to all firms (Arrow, 1962) or would

paper is that it studies how the choice between public and private ownership interacts with collusion opportunities and innovation. We show that such interactions could shed light on stylized facts, such as why the recent decrease in public ownership coincides with increased takeover activity (Doidge et al., 2016).

Our paper continues as follows. Section 2 describes the baseline model. Sections 3–5 contain our main results, extensions, and empirical implications, and Section 6 concludes. All proofs are in the Appendix.

2   Model

There are two firms, an innovator and an incumbent, operating in a two-period economy with three dates, $t = 0$, $t = 1$, and $t = 2$. Both firms are risk neutral and there is no discounting.

The technologies   At $t = 0$, the innovator has access to two technologies—an innovative (new) technology and an incumbent (old) technology. Neither technology requires an initial investment, but the innovator has the capacity to choose only one. The development of the new technology may not work out. Its prospects depend on the state θ, which determines the probability of positive cash flows. With probability $1 - \theta$, the innovator is unable to develop the new technology and cannot generate any cash flows. The probability (state) θ is uncertain at date $t = 0$ when the technology choice is made. It is commonly known that it can take on three values $\theta \in \{0, \theta_M, \theta_G\}$ where the ex ante probabilities of θ_M and θ_G are p_M and p_G, respectively, and where $0 < \theta_M < \theta_G < 1$. To start developing the new technology, the innovator needs to hire an R&D team and motivate it to exert effort $e \in \{0, 1\}$. By exerting effort, the R&D team can increase the likelihood of θ_M and θ_G to $p_M + \tau_M$ and $p_G + \tau_G$, respectively. However, the R&D team's effort is not verifiable, and by shirking (which leaves the probabilities of θ_M and θ_G unchanged at p_M and p_G), the R&D team saves on a non-monetary cost c.

At the interim date $t = 0.5$ of the first period, the innovator observes a non-verifiable signal that shows the value of θ. At this point in time, if the innovator has started the new technology, it can still abandon it and compete in the first period with the incumbent technology. We assume that the decision whether to abandon the new technology lies with

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allow some firms to price discriminate (Greenstein and Ramey, 1998); the extent of competition before or after innovation (Dasgupta and Stiglitz, 1980); the dynamics of R&D (Harris and Vickers, 1985); and whether innovation is preemptive (Gilbert and Newbery, 1982). Another key question is whether patenting is good for innovation (Kultti et al., 2007). See Gilbert (2006) for an extensive literature review.

the innovator, and not the R&D team.[7]

Unlike the innovator, the incumbent firm operates the old technology from the beginning of the first period. It can try to develop in addition the new technology, but it would incur a deadweight cost of k of diverting resources. This cost could further stand for the cost of cannibalizing the firm's existing business or the cost of acquiring a firm that has the necessary know-how to help develop the new technology. We denote the expected probability that the incumbent successfully develops the new technology with θ_{Inc}, and, for simplicity, we assume that no additional information about θ_{Inc} is revealed at $t = 0$.[8]

The two firms' cash flows are realized at $t = 1$ and $t = 2$, i.e., at the end of period one and two, respectively. If only one of the two parties successfully develops the new technology, it enjoys cumulative first-mover cash flows x_M ($\frac{x_M}{2}$ per period), while the other firm's cash flows are zero in both periods. If none of the firms is successful in developing the new technology, but the innovator has pursued it until the end of period one, the incumbent reaps the cumulative monopoly profits x_M ($\frac{x_M}{2}$ per period) from the incumbent technology, while the innovator generates zero cash flows in period one and goes out of business. If both firms use the old technology or successfully develop the new technology by the end of period one, collusion might come into play. Figure 1 summarizes the sequence of events in period one.

Coordination Problem if Both Firms Use the Same Technology What do we mean by collusion and how does it work? We stipulate that, in each period when using the same technology, both firms decide whether to collude (action C) or not collude (action NC). As emphasized in the introduction, we use the term "collusion" broadly to refer to any action or, respectively, lack of action that helps avoid head-to-head competition. For example, the firms may allow each other to pursue distinct strategies even if they face no technological hurdles that would stop them from competing.[9] The choice of action $\{C, NC\}$ affects the firms' cash flows, which are stochastic and realized at the end of the respective period. If both firms collude in a given period, their expected cash flows when utilizing the same technology in that period are x_C for each. If neither firm colludes, their

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[7]Allowing for an optimal allocation of the right to decide on the new technology's continuation could help improve the R&D team's effort incentives. However, renegotiations at $t = 0.5$ always lead to the same continuation decision: i.e., the new technology is continued if and only if its expected payoff is larger than that from the old one (given the information at $t = 0.5$). Because of this, the qualitative insights we discuss next remain unchanged.

[8]We want to capture the realistic situation where the incumbent may not want to pursue all innovation opportunities that the innovator pursues, e.g., because it may negatively affect its existing business. The deadweight cost k guarantees this.

[9]This aspect relates our paper also to the literature analyzing collusion when firms' products are not perfect substitutes (e.g., Chang, 1991; Ross, 1992).
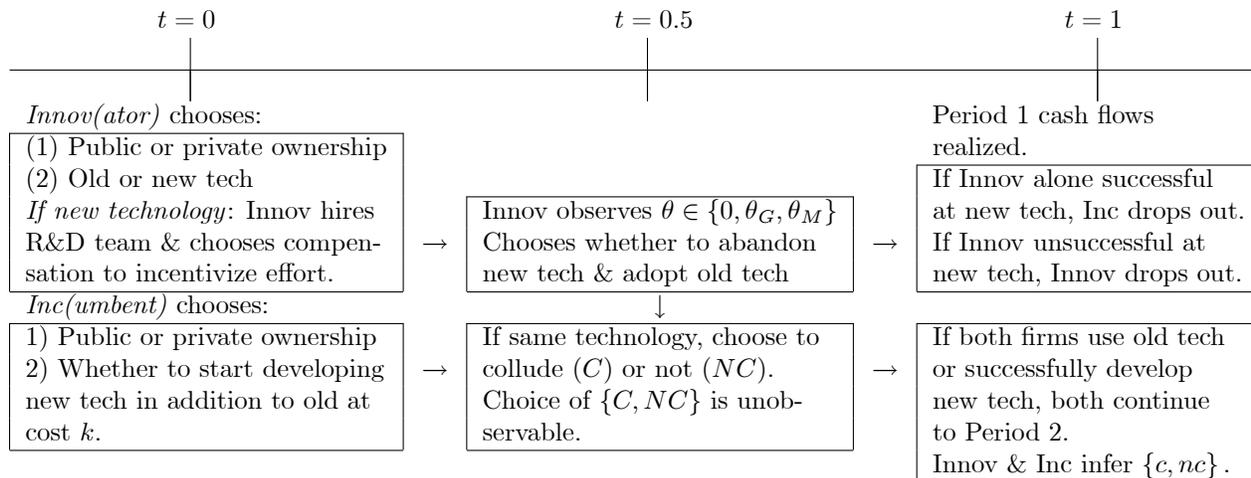
Figure 1: **Timeline of first period.** If both firms survive the first period, they operate the same technology in the second period and choose again whether to coordinate in the beginning of that period.

expected cash flows are lower: $x_{NC} < x_C$. If one of the firms tries to collude, while the other does not, the former firm's expected cash flow is $x_C - m$, while the latter firm's expected cash flow is bx_{NC}, with $m > 0$ and $b > 1$.

We assume that firms face a one-time cost K the first time they seek collusion, but no such cost in the following period. Specifically:

Assumption 1: $K > x_C - bx_{NC} \geq 0$.[10]

The first inequality introduces a prisoner's dilemma in a one-shot game (single period), making collusion over just one period impossible. The second inequality makes collusion potentially possible in a two-period setting.

A final condition we need is that choosing to collude should not always be preferable regardless of whether the other firm colludes:

Assumption 2: $x_C - m < x_{NC}$.

For simplicity, the expected cash flows x_C and x_{NC} (and the parameters m and b) are initially the same for both firms. In practice, they might differ depending on the firms' size and first-mover status. Where relevant, we will discuss the consequences of allowing the innovator and the incumbent to differ in size. Figure 2 summarizes the coordination problem in a game that would only consist of one period.

Information Structure and Public vs. Private Ownership   We assume that the decision whether the firm should be public or private is made at the beginning of the first

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[10]In the infinite horizon extension of this model, K can be set to zero and the first inequality in Assumption 1 is not necessary.

		Incumbent	
		C	NC
Innovator	C	$x_C - K, x_C - K$	$x_C - K - m, bx_{NC}$
	NC	$bx_{NC}, x_C - K - m$	x_{NC}, x_{NC}

Figure 2: **Benchmark 1:** Payoffs in a one-period game. Collusion is not sustainable. The only Nash equilibrium is (NC, NC)

period $(t = 0)$ and cannot be revoked until the end of that period. Neither firm's action C or NC is observable, but at the end of every period, each firm infers a signal $s = \{c, nc\}$ about whether or not the other firm has colluded. The signal is based on each firm's own cash flows and the information reported by the other firm. Note that since cash flows are stochastic (x_C and x_{NC} are the expected values), they are not fully informative about the firm's action. We denote the likelihood of making the wrong inference with $\varepsilon \in \left[0, \frac{1}{2}\right]$.

The critical difference between private and public ownership that we assume is that a public firm is obliged to report its cash flows.[11] This has two implications. First, the other firm's inference error weakly decreases, since its signal is based on more information. Second, the other firm can infer the signal that the public firm infers from its cash flows. In Section 4.3, we extend the model to account for voluntary reporting by private firms. Initially, we assume that the decision to develop the new technology is observable regardless of whether the firm is public or private. Subsequently, we show that our results are reinforced if being private allows the innovator the keep the incumbent in the dark whether it is developing the new technology (Section 3.4).

3 The Choice Between Public and Private Ownership

There are four main choices in this model: (i) whether the firms will collude when using the same technology; (ii) whether the firms start developing the new technology; (iii) whether the innovator abandons the new technology at $t = 0.5$ if it had started developing it at $t = 0$; and (iv) whether the firms choose public or private ownership.

In what follows, we show that public ownership facilitates collusion on the incumbent technology. However, the ability to collude could lead to a time inconsistency problem in which the innovator responds too aggressively (from an ex ante perspective) to unfavorable intermediate signals on the viability of the new technology, i.e., abandons it too often.

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[11]Though in what follows we speak of inferring signals from cash flows, public firms are obliged to report also other information indicative of past and future actions. At the expense of introducing additional notation, we could model these effects explicitly and derive ε from primitives using Bayes rule. However, the reduced-form notation is sufficient for our purposes.

		Incumbent	
		C	NC
Innovator	C	$x_C - \mathbf{1}_{NC}K, x_C - \mathbf{1}_{NC}K$	$x_C - \mathbf{1}_{NC}K - m, bx_{NC}$
	NC	$bx_{NC}, x_C - \mathbf{1}_{NC}K - m$	x_{NC}, x_{NC}

Figure 3: **Benchmark 2:** Second-period expected payoffs when firms make no inference errors about the first-period action of the other firm ($\varepsilon = 0$). The indicator function $\mathbf{1}_{NC}$ takes the value of one if the firm has not colluded in pediod one and zero otherwise. Apart from playing twice (NC, NC), we can now also support an equilibrium in which both firms play C in period one and play again C in period two if they observe that the first period actions are (C, C); otherwise they play NC.

We proceed as follows. First, we explain how collusion works and how it depends on being public or private. Subsequently, we analyze the choice between public and private ownership and how it interacts with the incentives to innovate.

3.1 Public Ownership as a Coordination Mechanism

Both firms' cash flows are higher if they manage to collude when using the same technology. However, colluding only in one period is not feasible. If one firm intends to collude, it is optimal for the other not to do so, as its expected cash flow from not colluding, bx_{NC}, is higher than that from colluding, $x_C - K$ (Figure 2). With two periods, collusion may be possible to sustain, but this depends on what the firms observe at the end of the first period. In the benchmark in which firms make no inference errors about the actions played by the other firm ($\varepsilon = 0$), colluding in both periods can be supported as an equilibrium (Figure 3). Specifically, the equilibrium candidate is that firms collude in period two if and only if they observe that both firms have colluded in period one. No firm has an incentive to deviate from this equilibrium candidate if the expected payoff from colluding over two periods and incurring K is higher than the highest deviation payoff, which occurs when a firm abandons collusion in the first period, followed by mutual non-collusion in the second period:

$$2x_C - K - (bx_{NC} + x_{NC}) > 0. \tag{1}$$

The key insight in what follows is that with inference errors ($\varepsilon > 0$), regardless how small, the ability to sustain a collusion equilibrium becomes disproportionately more difficult under private compared to public ownership. The advantage of public ownership is that it helps firms coordinate their future actions by forcing them to make their cash flows public.

Private ownership. Consider the following equilibrium candidate: Both firms collude

in period one, and collude in period two if and only if they infer from their cash flows that the other firm has colluded as well (i.e., their signals are c). Note that there can be no (pure strategies) equilibrium candidate in which signals nc do not trigger abandonment of collusion in period two. Without a trigger that punishes a firm for signals indicating that it has not colluded, it would be optimal for it to deviate in period one from the conjectured collusive equilibrium.

Private ownership hampers collusion for two reasons. First, the inference error ε is higher than with public ownership, which makes it less likely that collusion in period two can be sustained. The expected payoff from colluding in period two, following signal c, is higher than from not colluding if

$$(1 - \varepsilon) x_C + \varepsilon (x_C - m) > (1 - \varepsilon) b x_{NC} + \varepsilon x_{NC}. \qquad (2)$$

These expected payoffs take into account that, even if a firm colludes in period one, the other firm infers signal nc with probability ε, which prompts that firm not to collude in period two. Such wrong inferences, leading to a breakdown in collusion, make it also less attractive to start colluding in period one.[12]

Second, even ignoring that private ownership increases the inference error, collusion is more difficult to achieve, as it is hard for a private firm to commit to a trigger strategy of abandoning collusion when its cash flows are low (i.e., when it observes signal nc). The reason is that in a conjectured collusive equilibrium, a signal indicating deviation can only be wrong and must be due to the inference error — i.e., the low cash flows must be due to bad luck rather than to a deviation by the other firm. Thus, the private firm may neglect this signal and stick to the collusive strategy. What makes continuing to collude ex post more profitable is that, if the other firm has colluded in the first period, it expects that the private firm's cash flows are most likely high. In this case, both firms would benefit from continuing to collude. However, crucially, this ex post incentive not to go through with the threat of abandoning collusion invites the other firm to deviate ex ante in period one, making a conjectured collusive equilibrium unsustainable.

The problem that a private firm that has colluded in the first period might ignore its signal and collude also in period two is most pronounced when both firms' signals are independent. In this case, if a private firm colludes in period one, it expects that the other firm receives signal c with probability $1 - \varepsilon$ and, thus, colludes also in period two with such probability. Hence, *regardless of its signal*, the private firm's expected payoff from

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[12]To get the expected payoff from colluding in period one, add x_C to the left-hand side of (2). To get the deviation payoff from not colluding twice, add $b x_{NC}$ to the right-hand side of (2).

colluding is equal to the left-hand side of expression (2), and the expected payoff from not colluding is equal to the right-hand side of expression (2). Thus, if the firm colludes after inferring c, it has the same incentive to collude after inferring nc — in a collusive equilibrium, this signal must anyway be due to the inference error. As a result, with independent signals, the threat of abandoning collusion in case of low cash flows is not credible for *any* inference error $\varepsilon > 0$.

This problem is ameliorated if both firms' signals are dependent and if that implies that, after observing nc, the conditional likelihood $\widetilde{\varepsilon}$ that also the other firm has inferred nc is higher compared to after observing signal c (in this case the inference error ε in (2) differs depending on whether the firm infers c or nc). Then, if $\widetilde{\varepsilon}$ is sufficiently high, the expected payoff from abandoning collusion in period two may become higher than that from colluding (as $x_C - m < x_{NC}$). In this case, the threat of abandoning collusion after observing signal nc could become credible (see Appendix).[13]

Public ownership. By committing the firm to report its cash flows, public ownership circumvents the problem that a private firm has an ex post incentive to neglect signal nc. Though also under public ownership the firms know that in a conjectured collusive equilibrium, low cash flows must be due to bad luck rather than a deviation by the other firm, the key difference is that a public firm must report its low cash flows. This helps firms coordinate on abandoning future collusion. Specifically, when a public firm reports low cash flows, the other firm knows that the public firm is supposed to abandon collusion. Anticipating this, it is better off abandoning collusion also itself. Thus, it becomes mutually optimal for both firms to abandon collusion.[14] With credible punishments now in place, a collusive equilibrium can be sustained.

Specifically, the equilibrium candidate under public ownership can be amended as: collude in the first period, and collude in the second period if and only if *both* firms observe signal c. In this case, if a firm observes signal nc, this becomes common knowledge and the expectation that it will not collude in period two makes it, indeed, a mutual best response for both firms not to collude in that period. The opposite holds if both firms observe signal c.[15] Thus, the commonly observed signal becomes a coordination device on what action to take in period two.

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[13]In practice, signal dependence could arise if both firms experience an unobservable common demand shock. It could also arise if firms play mixed strategies (Bhaskar and Van Damme, 2001).

[14]Clearly, public firms' obligations to publish material information informative of past and future actions further helps coordinate actions.

[15]Observe that signal dependence is irrelevant for this argument. Furthermore, note that since signals are imperfect, equilibrium "price wars" occur despite the fact that both firms coordinate. However, this threat is needed to discipline both firms to start coordinating in the first place.

What further simplifies collusion is that the inference errors decrease. Subtracting the highest deviation payoff, which results from not colluding in both periods, from the equilibrium expected payoff, no firm has an incentive to deviate if

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\begin{aligned}
0 \ \leq \ & x_C - K + (1 - \varepsilon)^2 \, x_C + \left(2\varepsilon - \varepsilon^2\right) x_{NC} \\
& - \left(bx_{NC} + (1 - \varepsilon) \, \varepsilon b x_{NC} + \left(1 - \varepsilon + \varepsilon^2\right) x_{NC}\right).
\end{aligned} \tag{3}
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Naturally, expression (3) becomes easier to satisfy when the inference errors decrease, and it reduces to the one in (1) for $\varepsilon \to 0$.

Proposition 1 *(Public ownership as a collusion mechanism): Collusion is easier to attain with public than with private ownership.*

Henceforth, we assume that collusion is always achieved under public, but never under private ownership. Thus, implicitly we assume that (i) with public ownership, firms choose the collusion equilibrium (rather than not colluding in both periods, which is also an equilibrium); and (ii) firms' signals are sufficiently independent and/or the inference errors are sufficiently large, making collusion under private ownership infeasible.

3.2 Abandoning the New Technology with Public and Private Ownership

Given the option to increase the firm's cash flows through collusion with public ownership, one might wonder why not all firms go public in our model. The answer is that collusion might undermine innovation incentives. Instead, choosing private ownership can serve as a commitment mechanism. To make the point, suppose for now that the incumbent is public and that it is common knowledge that it does not engage in innovation.

The problem we want to highlight is that the innovator may choose to abandon the new technology for different realizations of θ depending on whether the firm is public or private. In particular, the temptation to abandon the old technology is especially strong with public ownership, as then both firms can collude and obtain high profits from the existing technology. The trade-off is one between ex ante and ex post optimality.

Though the option of early termination might be valuable ex post, it could reduce the R&D team's incentives to exert effort ex ante. Let $\mathbf{w} = \{w_0, w_A, w\}$ be the contract the innovator offers the R&D team, which pays w_0 in case of zero cash flows, w_A in case the new technology is abandoned, and w in case the new technology is successful and yields positive cash flows. Note that the R&D team's wage can only be contingent on what is

verifiable, i.e., the innovator's decision to continue or abandon the new technology and the subsequent cash flows. Since the innovator is protected by limited liability, we can set $w_0 = 0$. We allow that the contract is renegotiated at $t = 0.5$, in which case γ denotes the fraction of the additionally generated surplus that the R&D team can negotiate for itself.

The R&D team's incentive constraint is

$$U\left(\mathbf{w},1\right) - c \geq U\left(\mathbf{w},0\right), \tag{4}$$

where $U\left(\mathbf{w},e\right)$ denotes the R&D team's expected payoff depending on its effort e. Since, by optimality for the innovator, (4) will be satisfied with equality and the R&D team's outside option is zero, $U\left(\mathbf{w},0\right)$ represents the R&D team's agency rent. It is straightforward to show that it is optimal to pay the R&D team only if the new technology is continued (i.e., $w_A = 0$).

The tension between ex post optimality and ex ante incentives arises because the abandonment of the new technology in case of an unfavorable θ realization has two effects on effort. One is the standard positive disciplining effect of not getting paid ($w_A = 0$) if the new technology is abandoned. The strength of this effect increases in the impact of effort (τ_G) on the likelihood of landing in state θ_G. However, there is a second effect, which is negative. Exerting effort increases also the likelihood of state θ_M by τ_M. Since this effort is wasted in case the new technology is abandoned in state θ_M, such abandonment makes it more difficult to satisfy the R&D team's incentive constraint. We show that this negative effect dominates if $\tau_M > \tau_G \frac{p_M}{p_G}$. Then, the better abandonment option at $t = 0.5$ under public ownership makes it more expensive to motivate the R&D team compared to private ownership.

The key insight is that the resulting time inconsistency problem of being unable to commit not to abandon the new technology in case of state θ_M is more acute under public ownership, as then the outside option of colluding on the existing technology is ex post more attractive. This tension between ex ante and ex post efficiency could make private ownership ex ante preferable. This occurs if the ex ante expected profitability of the new technology is sufficiently high (i.e., p_G is high). Then, the innovator needs to pay the R&D team a higher wage (as $\tau_M > \tau_G \frac{p_M}{p_G}$), while benefiting less from the better collusion possibilities of public ownership in states $\theta = \{0, \theta_M\}$. Hence, the time inconsistency problem is particularly costly when the new technology is sufficiently attractive.

Proposition 2 *(Time inconsistency with public and private ownership): Suppose that innovation comes only from the innovator. The innovator's inability to commit not to abandon the new technology in case of signal θ_M gives rise to a time inconsistency problem.*

There is a threshold for $\widehat{p}_G$, such that the innovator prefers public ownership if $p_G < \widehat{p}_G$, and private ownership otherwise.

Proposition 2 implies that private ownership is preferable only if the new technology is sufficiently attractive. This is because, if the new technology is only marginally valuable, the firm is better off having the option to abandon and collude on the existing technology. Public ownership is then optimal. Note that the choice between public and private ownership for the incumbent is trivial: Public ownership dominates, because it gives the firm the option to coordinate on the existing technology and may discourage the innovator from developing the new technology.

3.3   Competition for Innovation and the Public-Private Choice

Suppose now that it is common knowledge that the incumbent also works on developing the new technology. The incumbent firm chooses do so if its success likelihood θ_{Inc} is sufficiently high to compensate it for the cost k of diverting resources.

Competition on the new technology has two key effects that both increase the attractiveness of public ownership. First, if both firms successfully develop the new technology, they can benefit from colluding not to compete away each other's profits. Thus, collusion can have a positive effect on innovation, as it increases the reward in case of success. This effect becomes increasingly valuable for the innovator, the more likely it is that the incumbent successfully develops the new technology (i.e., the higher is θ_{Inc}).

Second, when the incumbent also tries to develop the new technology, the option to abandon its development at $t = 0.5$ becomes less attractive for the innovator. In the extreme, in which the incumbent is always successful at innovation, the only way for the innovator to survive is to continue innovating regardless of its interim signal. In this case, being public is always preferable, as it would help coordinating to avoid competition if both firms successfully develop the new technology.

Proposition 3 *(Competition for innovation) Suppose that both firms compete to develop the new technology. An advantage of public over private ownership is that the firms can collude not only on the incumbent, but also on the new technology if the latter is successfully developed by both firms. There is a threshold $\widehat{p}'_G(\theta_{Inc})$, such that the innovator prefers public ownership if $p_G < \widehat{p}'_G(\theta_{Inc})$ and private ownership otherwise. This threshold p'_G increases in the incumbent's success likelihood θ_{inc}, so that for a sufficiently high θ_{inc} it is always better for the innovator to be public.*

Since, in practice, the likelihood that the incumbent successfully develops the new technology is likely to be correlated with that of the innovator, assume for simplicity that $\theta_{Inc} = p_M \theta_M + p_G \theta_G + \delta$ (where δ could be positive or negative). With such correlation, we obtain a U-shaped relationship between the attractiveness of innovation (as captured by p_G) and the attractiveness of public ownership for the innovator:

Corollary 1 *The innovator's choice between public and private ownership is U-shaped in the new technology's attractiveness. If that attractiveness is:*
(i) low, it is optimal to choose public ownership;
(ii) medium, it is optimal to choose private ownership;
(iii) high, it is optimal to choose public ownership.

The results of Corollary 1 can also be related to the incumbent's cost k of starting to innovate. For example, if for the incumbent the cost of cannibalizing the firm's existing business or externally acquiring the human capital or skills needed to develop the new technology are very large (k is high), the incumbent would not innovate. Then, case (iii) will not apply, because the incumbent would not be innovating.

3.4   Discussion: Other Channels and Interpretations

Reporting on Development of New Technology   Our analysis assumes that the firms know whether their competitor is developing the new technology. A further difference between public and private ownership is that significant new investments or changes in strategy must be reported by public, but not by private, firms.[16] Thus, very much in line with the old financial intermediation and IPO literature (Bhattacharya and Ritter, 1983; Bhattacharya and Chiesa, 1995), a firm may prefer private ownership to avoid alerting its rival that it is developing a new technology. Leakage of such information could reduces the expected profitability of sticking to the existing technology for the incumbent firm and could encourage it to start developing this technology as well. This insight reinforces our result that for intermediate expected profitability of innovation (i.e., values for which it is not sufficiently profitable for the incumbent to start developing the new technology), the innovator will choose to stay private — not only because it helps it commit to a long-term innovation strategy, but also because it makes it more likely to avoid competition on that strategy. However, if innovation is sufficiently attractive, so that the incumbent enters anyhow, being able to coordinate on the development of the new technology (e.g., what

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[16]We thank Merih Sevilir for suggesting this discussion.

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aspects to develop) becomes important. Thus, we see our theory of coordination as one complementing rather than contradicting prior work.

The incumbent may also be strategic about reporting working on the development of a new technology, as such reporting has an effect on the innovator. A report by the incumbent that it is working on developing the new technology decreases the expected profitability of investing in innovation and, with a positive investment cost (not modelled in our setting) may discourage the innovator from investing in innovation. However, once this investment cost is sunk, the innovator is less likely to abandon innovation. Abandoning is then less attractive, as it could leave the innovator with zero cash flows if the incumbent develops the new technology (Proposition 3).

Finally, it is worth noting that, even if a firm prefers to be private while still developing a technology, once it starts using it and the new technology becomes the new standard, the firm may benefit from going public and coordinating with its rivals. This observation is in line with life-cycle theories of the firm in which a firm goes public once it has developed sufficiently.

Types of Coordination and Alternative Interpretations   Our model does not differentiate between legal and illegal coordination. However, in practice, coordination on existing technologies (case (i) of Corollary 1) is more likely to be deemed illegal than coordination on new technologies (case (iii)), as in the former case the perceived harm to consumers is typically greater. Instead, when it comes to innovation, regulators may be more likely to tolerate coordination, as a promise of higher profits (at least for a time) is usually considered necessary to stimulate innovation. Relating to the preceding discussion, when firms coordinate already in the development stage of a new technology, it may also be easier to have subsequently genuinly different products and services that allow them to avoid direct competition. This would be more difficult with incumbent technologies that are well understood and can easily be copied.

Our model highlights the importance of a commitment to the regular and credible reporting of information. The model applies best to concentrated industries in which there is information asymmetry regarding firm strategies. In such cases, the information provision mandated by public ownership may help inform rival firms. More broadly, we could rephrase Propositions 1-3 as a firm choosing whether to participate in a mechanism, subsequently forcing it to report information about itself. Apart from public ownership, such a mechanism is offered also by industry associations collecting price and trade statistics information, which are then made available to members.[17] Thus, when it comes to coor-

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[17]A much-cited example is The Open Competition Plan. This plan was a central clearing house for

dinating on prices or quantities, such information may substitute for the benefit of public ownership. Public ownership, however, may remain beneficial when it comes to coordinating on future strategy and innovation.

4   Extensions: Size, Equity Stakes, and Voluntary Reporting

Our baseline analysis made several simplifying assumptions that helped us distill the main novel economic forces. Some of these assumptions included that the innovator and the incumbent were of the same size and that going public entailed no costs for the innovator. In what follows, we relax these assumptions and, based on this, derive several additional predictions. Additionally, we discuss buying equity stakes and voluntary reporting as alternative ways of achieving coordination and compare the implications for innovation.

4.1   Size, Innovation, and Coordination

Consider, first, the effect of firm size. In this section, we extend our baseline model by introducing a date $t = -1$ at which the innovator can choose to operate at a larger scale (for simplicity, at no additional cost). Let $\varphi > 1$ be the scaling parameter, which increases expected profits to φx_{NC}, φx_C, and φx_{FM}. Thus, scaling up does not affect the relative attractiveness of colluding versus not colluding for the innovator. However, the innovator's size matters for the incumbent, as its losses from non-collusion are higher when the innovator chooses to be large. Specifically, the incumbent's profits fall by φm, and we assume that $x_C - \varphi m < x_{NC} < x_C - m$. That is, Assumption 2 is satisfied if the innovator is large, but not if it is small. Then, if both firms use the same technology and the innovator chooses to remain small, the incumbent chooses the colluding action regardless of the action taken by the innovator. Intuitively, it is not worth to start a price war with a small rival who chooses to be a marginal player.

A small innovator can then free ride and choose non-collusion while expecting that the collusive action will be the dominant strategy for the incumbent. Clearly, this could make remaining small and "staying under the radar screen" more profitable than growing large and having to coordinate with the incumbent. If the innovator chooses to remain small, the choice between public and private ownership no longer affects the action C

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information on prices, trade statistics and practices, with the aim of keeping all members fully and quickly informed of what the others have done. Though this plan was struck down by antitrust authorities, there are still varoius industry association offering similar services.

or N. Furthermore, because the incumbent chooses to behave cooperatively, the innovator's incentives to abandon the new technology and adopt the incumbent's technology are higher compared to when it would have chosen to be large. This has a negative impact on innovation.

Proposition 4 *If the innovator remains small, it is more likely to abandon the new technology. Remaining small is optimal if b is above a threshold $\bar{b}(\varphi)$ as defined in the Appendix.*

An immediate corollary of Proposition 4 is that introducing a cost of going public will have the following effects:

Corollary 2 *Imposing a cost of public ownership makes it more likely that the innovator chooses to remain small (and private) and to abandon the new technology's development. Without such cost, the innovator is more likely to grow large and choose public ownership to soften head-to-head competition with the incumbent.*

4.2 Coordination Through Equity Stakes

Suppose that the incumbent buys a non-controlling stake β in the innovator, which gives him a proportional right to the firm's cash flows, but otherwise no control rights. A rationale for buying a non-controlling stake is that it could allow the incumbent to observe the innovator's cash flows, even if the innovator is private. Following the same arguments as in Proposition 1, this would imply that collusion can be achieved on the existing (incumbent) technology provided that the incumbent is public and, thus, also its cash flows can be observed by the innovator.

Both public ownership and buying a non-controlling equity stake discourage innovation by allowing for collusion on the incumbent technology. However, buying an equity stake has a further negative effect on the incumbent's innovation incentives. Specifically, if the innovator engages in the new technology, the incumbent benefits from it via its non-controlling equity stake, which lowers its own incentives to innovate. This negative effect is stronger, the larger the incumbent's stake.

We, thus, obtain a natural complement to the standard scenario analyzed in the literature in which the incumbent buys a controlling stake, which makes coordination automatic and collusion issues no longer relevant. Similar to Phillips and Zhdanov (2013), this case would feature a natural specialization in which the incumbent firm's incentives to innovate are even lower, while those of the innovator are higher compared to when the firms operate

independently. Specifically, the incumbent has now the option to adopt the new technology, even without developing it itself, as long as the innovator is successful. This further decreases its own incentives to develop it. However, since collusion is no longer relevant, the two firms will not compete away the first-mover profits on the new technology. What is more, since the opportunity cost of abandoning the new technology in order to collude on the existing one is also no longer present, the innovator can keep developing the new technology even after observing signal θ_M. The latter two effects increase the likelihood that the innovator develops the new technology.

Proposition 5 *(i) Buying a non-controlling equity stake in the innovator can help achieve collusion on the existing technology, but reduces the incumbent's innovation incentives. (ii) Buying a controlling equity stake further reduces the incumbent's innovation incentives, but it increases the likelihood that the innovator develops the new technology.*

Though buying equity stakes and public ownership can both lead to collusion, they are not perfect substitutes, as they have different effects on innovation incentives. Thus, one would expect that imposing additional (e.g., regulatory) costs on public ownership would lead to an increase in firms buying equity stakes as an alternative means of achieving coordination.

Corollary 3 *Imposing a cost of public ownership increases the likelihood that incumbents acquire controlling or non-controlling equity stakes as an alternative means of avoiding competition.*

4.3   Private Ownership and Voluntary Reporting

We have assumed so far that public ownership effectively commits the firm to make its signal $s \in \{c, nc\}$ public. However, a private firm could voluntarily report its cash flows. The key difference is that regulation governing public firms has explicit requirements regarding the type and quality of information that needs to be made public. No such regulation applies to private firms, and when reporting requirements exist, the required quality is typically much coarser than that for public firms. Furthermore, though outside the model, it is worth mentioning that third parties, such as stock analysts, actively engage in information production about public firms, which adds to the transparency and the credibility of information about such firms. For these reasons, we let $\eta \in [\underline{\eta}, 1]$ denote the probability with which outsiders make a correct inference about the private firm's signal s. We model η as being a choice variable for the private firm, with the lower bound $\underline{\eta} \geq \frac{1}{2}$ defining the limits to communicating less precise information.

In what follows, we analyze the consequences for collusion when both firms operate the same technology. We assume that one of the firms is public, while the other private, and ask whether the private firm could mimic the information revelation that would apply in case of public ownership. We maintain Assumption 2.

Consider the same candidate equilibrium as in Section 3.1 according to which each firm colludes in period one, and colludes again in period two if and only if it infers signal c following period one and infers from the information reported by the other firm that it has also observed c. Suppose that both firms follow the conjectured equilibrium strategies of colluding in the first period, and suppose that at the end of that period the public firm infers that the private firm's signal is c (which becomes then common knowledge). If the private firm infers signal nc from its cash flows, we know from Section 3.1 that it has incentives to neglect this negative signal and collude again. Consider, therefore, the consequences of adding noise to the private firm's report: With probability $1-\eta$, the public firm infers c and colludes, and with with probability η, it infers nc and does not collude. Hence, the private firm's payoff from colluding in period two is $(1-\eta)x_C + \eta(x_C - m)$, while from not colluding $(1-\eta)bx_{NC} + \eta x_{NC}$. Two insights follow immediately. First, in both cases, the private firm's period-two payoff increases from adding noise to its report when its cash flows are low. This is because, the private benefits when its counterpart behaves cooperatively regardless of whether it intends to deviate from collusion. Thus, following low cash flows in period one, the private firm will choose to add the maximum noise to its report $\eta = \underline{\eta}$. Second, comparing the payoffs of colluding and not colluding again in period two, colluding is ex post beneficial if

$$\eta \leq \eta^* \equiv \frac{x_C - bx_{NC}}{x_{NC} - bx_{NC} + m} \tag{5}$$

Hence if $\underline{\eta} \leq \eta^*$, the private firm will choose to collude also in the second period even if it infers nc. But then, going back to period one, we have again the problem that, expecting this behavior, the public firm will not start colluding. Thus, collusion cannot be sustained.

Even if (5) is not satisfied ($\underline{\eta} > \eta^*$), the private firm's ex post incentive to add the maximum level of noise to its report when its cash flows are low reduces the public firm's payoffs from following the proposed equilibrium strategy in period one relative to one in which it does not collude in both periods. Thus, also with voluntary reporting, we continue to obtain that private ownership reduces the likelihood of collusion.

Proposition 6 *A private firm that engages in voluntary reporting has an incentive to add noise to its reports when its first-period cash flows are low. This reduces the opportunities*

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for collusion.

5 Empirical Implications

First, we discuss the implications of our model for collusion on existing technologies (Implications 1–3). Then, we discuss the implications of public and private ownership for innovation (Implications 4–7). Though providing empirical support for our predictions is beyond the scope of this paper, in Appendix B, we discuss some tentative empirical evidence consistent with our predictions that public firms are more likely to collude to avoid competition and that there would be a U-shaped relationship between the attractiveness of innovation and that of public ownership.

5.1 Empirical Implications

Public ownership and competition avoidance. The question why private firms choose to go public is long-standing in the finance literature. Firms that go public are typically larger and the going public decision typically coincides with important turning points in the firms' life-cycle. Key reasons for going public discussed in the literature include improving diversification opportunities and liquidity, raising capital for investment, exploiting favorable market conditions, facilitating acquisitions, and making the firm more visible (Ritter and Welch, 2002). We add one more reason for why a larger firm at a turning point in its life-cycle may seek public ownership, which is surprisingly neglected in prior work: facilitating collusion and coordination of strategies to avoid head-to-head competition. The effects should be especially pronounced in concentrated industries, as collusion would be easier to achieve with a smaller number of players.

Implication 1 *By committing firms to strict disclosure requirements, public ownership helps firms to coordinate strategies and avoid competing with each other.*

By endogenizing the choice of public ownership, our paper shows that firms choose public ownership if they fear that head-to-head competition will erode their future profits. As emphasized, our notion of collusion encompasses more broadly also seemingly legal strategies, such as focusing only on a specific aspect of a technology, which ultimately helps firms to avoid competing with each other. This idea could help shed light on puzzling stylized facts, such as why profit margins in public tech, biotech, and pharma firms are hard

to square with competitive product markets. After all, the potential leakage of valuable information to competitors should be especially painful for such firms.[18]

Recent advances in information technology have made it easier for private firms to disseminate valuable information about themselves to outsiders. With advances in new technologies, such as the blockchain, that further improve the verifiability of information, we expect that collusion opportunities may become easier also for private firms (Proposition 6) — a prediction shared also by Cong and He (2018).[19] This would negatively affect competition.

Implication 2 *(i) Advances in information technology that ease the credible dissemination of information would improve coordination and collusion prospects under private ownership, which would allow also private firms to retain high margins without going public. (ii) Other mechanisms that could play a similar role to public ownership for sharing information include price comparison websites or industry associations collecting and distributing price and quantity data.*

Public ownership is one important way to help firms commit to reporting regularly information about themselves regardless of whether it is in their best interest ex post. However, as noted in Section 3.3, we could reformulate Propositions 1-3 as a firm choosing between being a member of an industry association collecting price and quantity data from members and making these data available to members. Somewhat ironically, firms could also coordinate their prices when their products and services are tracked by price comparison websites. All these mechanisms suggest that calls to limit (minority) common ownership to spur competition (Azar et al., 2016) may only be a partial solution.

Recent empirical work has argued that an increase in the information disclosure requirements and compliance costs is part, but not the whole, explanation for the decrease of public ownership in the U.S. In particular, it has been pointed out that the decline of public ownership coincides with an increase in merger and acquisition activity (Doidge et al., 2016). The latter is interesting, as it suggests that firms may be shifting from one way of achieving coordination to another (Corollary 3).

Implication 3 *An increase in the cost of public ownership will increase the propensity of firms to buy equity stakes or acquire firms as an alternative coordination mechanism to public ownership.*

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[18]See also "Larry Summers: Corporate profits are near record highs. Here's why that's a problem," Washington Post, March 30, 2016.

[19]Cong and He (2018) argue that, by serving as record keepers, firms active on the blockchain may be better able to infer aggregate business conditions and detect deviations. This could help sustain collusive equilibria.

An interesting insight relating to our earlier comment that a higher industry concentration makes collusion easier is that an increase in takeover activity increases concentration, which could in turn increase the attractiveness of public ownership as a coordination device.

Public ownership and innovation. Our second set of implications investigates how collusion and the choice between public and private ownership interacts with innovation incentives. One of our first key insights is that private ownership could help overcome the time-inconsistency problem associated with the long-term pursuit of innovation. Our new angle is that, by making it harder to coordinate on existing technologies, private ownership reduces the temptation to abandon the development of a new technology in case of early difficulties (Proposition 1).

Implication 4 *By making it more difficult to coordinate with rivals on existing technologies, private ownership helps firms resist the temptation to abandon the development of new ones in the face of early difficulties.*

However, a higher tolerance for failure is not necessarily in the best interest of the innovator. First, if the new technology is not expected to be very profitable, the innovator might prefer to have the option to collude on the existing technology and choose public ownership (Corollary 1). This hurts innovation, but benefits the innovator. Second, private ownership might even be bad for innovation if the innovator faces competition on innovation from the incumbent. Then the opportunity to collude on the new technology might spur innovation incentives. Given these considerations, our key prediction is that private ownership will be unambiguously better only when the innovation's expected profitability is intermediate. Instead, if innovation opportunities either do not appear attractive or appear very attractive, public ownership will dominate.

Implication 5 *Public ownership dominates private ownership (i) if the expected profitability of the new technology is low, so that the value of the option to fall back on the high-margin existing technology is high; or (ii) if the expected profitability of the new technology is very high (inducing also the incumbent to start developing it). Then, the innovator could benefit from coordinating with the incumbent on the new technology. For intermediate values, private ownership is more beneficial, as it helps to reduce the time inconsistency problem of not being able to commit not to abandon prematurely the new technology.*

The predicted U-shaped relation in Implication 5 could shed light on the mixed empirical evidence that suggests that public firms may appear both leaders and laggards in innovation. On the positive side, a simple look at Kogan et al.'s (2017) dataset reveals that about 40% of patents produced in the 40 years between 1970–2010 are by public firms, and for every year of issue, the mean and median citations of patents by public firms are higher than those by non-public entities. Indeed, Acharya and Xu (2017) find that public firms are more innovative (though they attribute this to public firms' better access to capital) and Feldman et al. (2018) find that public firms invest more in R&D than comparable private firms. On the negative side, Gao et al. (2018) find that public firms may engage less in explorative innovation. Bernstein (2015) provides a mixed picture by documenting that public firms substitute internal innovation with acquiring new human capital and external innovation. Our predicted U-shaped relation reconciles such contradictory findings not only by explaining why public firms may appear less innovative, but also by highlighting that if a new technology is expected to be highly profitable, public ownership could help firms by allowing them to coordinate on that technology.

In the spirit of the old idea that monopoly profits can help spur innovation, Proposition 5 predicts that, by helping firms avoid competition, public ownership could improve innovation incentives:

Implication 6 *Public ownership sharpens the incentives to innovate when both innovators and incumbents work on developing new technologies.*

Implications 5-6 imply a U-shaped relation between the attractiveness of innovation and that of public ownership. We offer some preliminary evidence for this relation in the next section. Finally, based on Proposition 4, we have the following prediction about how the cost of public ownership affects the dynamics of smaller innovative firms:

Implication 7 *An increase in the costs of going public makes it more likely that innovators remain small and prematurely abandon innovation.*

What Implication 7 alludes to is that reduced ability to go public and coordinate with rivals could lead innovative firms to stay small to avoid triggering head-to-head competition from incumbents.

6   Conclusion

We develop a model that shows that the transparency that comes with public ownership helps facilitate the avoidance of competition. Such avoidance does not need to point at

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illegal types collusion (leading to antitrust concerns), but could involve perfectly legal strategies. Avoiding competition is arguably the main focus of the strategy literature, and a legitimate objective of running businesses. For firms, such strategies can be particularly valuable if they preserve high margins on existing (commoditized) technologies.

However, being able to collude on an existing technology is a double-edged sword as it may encourage innovators to prematurely abandon the development of new technologies in case of early difficulties. This temptation to abandon the new technology is more acute under public ownership, because, by facilitating collusion on the incumbent technology, it makes abandonment a more attractive exit-option. Hence, private ownership helps to commit to the long-term pursuit of innovation and improves incentives.

Taking these results as a starting point, we derive a number of novel implications about a firm's choice between public and private ownership. We find that there is a U-shaped relationship between the new technology's expected profitability and the attractiveness of public ownership. If the profitability is low, the option to collude on the incumbent's technology is very valuable, and public ownership dominates. However, if the new technology's expected profitability is higher, being able to commit not to abandon it in the face of early difficulties becomes more valuable. In that case, private ownership dominates. If the attractiveness of innovation becomes even higher, so that it attracts interest also by the incumbent, public ownership becomes dominant again, as it could help firms coordinate on the new technology if they develop it simultaneously.

Our analysis highlights three further aspects. First, size matters. Since large incumbents would not bother to respond to small rivals, small innovators will tend to abandon the development of new technologies faster even under private ownership, as they can free ride on the high margins of the incumbent technology. This could create incentives to remain small and private to avoid head-to-head competition with incumbents. Second, though collusion can also be achieved through equity stakes, such stakes are an imperfect substitute to public ownership, as other effects on innovation incentives come into play. Third, collusion would be difficult to achieve through voluntary reporting, as firms would have ex post incentives to add noise to their reports.

We offer some preliminary evidence that supports our basic premise that public ownership facilitates collusion and supports the prediction that there is a U-shaped relation between the attractiveness of innovation and that of public ownership. For future research, it would be interesting to expand on this evidence and further empirically investigate the relationship between collusion in public firms and its effect on innovation—not only in terms of investment, but also in terms of outcomes and types of innovation (e.g., explorative vs. exploitative).

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Appendix A: Proofs

Proof of Proposition 1. It only remains to show that colluding under private ownership is feasible if signals are sufficiently correlated. Let $\{C_i, NC_i\}$ and $\{c_i, nc_i\}$ denote firm i's actions and signals in period one. As argued in the main text, firm 1 prefers to collude after observing signal c_1 if

$$
\begin{aligned}
&(1 - \Pr(c_2|C_1, C_2, c_1))\, x_C + \Pr(c_2|C_1, C_2, c_1)\, (x_C - m) \\
&> \quad (1 - \Pr(c_2|C_1, C_2, c_1))\, b x_{NC} + \Pr(c_2|C_1, C_2, c_1) x_{NC}
\end{aligned} \tag{6}
$$

and prefers not to collude after observing signal c_2 if

$$
\begin{aligned}
&(1 - \Pr(c_2|C_1, C_2, nc_1))\, x_C + \Pr(c_2|C_1, C_2, nc_1)\, (x_C - m) \\
&< \quad (1 - \Pr(c_2|C_1, C_2, nc_1))\, b x_{NC} + \Pr(c_2|C_1, C_2, nc_1) x_{NC}.
\end{aligned} \tag{7}
$$

The equilibrium can then be supported if the expected payoff from colluding in period one and doing so again in period two (if and only if observing signal c) is higher than the expected deviation payoff from not colluding in both periods

$$
\begin{aligned}
0 \;\leq\; & x_C - K + \Pr(c_1, c_2|C_1, C_2) x_C + (1 - \Pr(c_1, c_2|C_1, C_2))\, x_{NC} \\
& - (b x_{NC} + \Pr(c_1, c_2|NC_1, C)\, b x_{NC} + (1 - \Pr(c_1, c_2|NC_1, C))\, x_{NC}).
\end{aligned} \tag{8}
$$

Omitting the details, it is straightforward to show that satisfying conditions (6)–(8) is possible if the signal correlations is sufficiently strong and the inference errors are sufficiently small.[20] **Q.E.D.**

Proof of Proposition 2. Define y_C to be the innovator's two-period payoff when both firms use the incumbent technology and collude, and let y_{NC} be expected payoff when they do not collude. There is a trade-off between public and private ownership when the continuation decision differs for $\theta = \theta_M$. Suppose, therefore, that $\theta_G x_M > y_C > \theta_M x_M > y_{NC}$ (note that there can be no single-period collusion on the new technology in period two). We treat the remaining cases at the end of the proof. In what follows, we consider in turn public (collusion) and private (non-collusion) ownership. Observe that when the new technology is abandoned, the R&D's wage cannot be made contingent on θ, as θ is non-contractible.

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[20]Details in terms of primitives are available upon request.

Public ownership and collusion at $t = 0.5$. The innovator takes the ex post efficient decision to abandon the new technology and collude with the incumbent after observing θ_M if $y_C - w_A > \theta_M (x_M - w)$. Since $\theta_M x_M < y_C$, a sufficient condition is that $\theta_M w \geq w_A$. Suppose for now that this is satisfied (below we show that it is, as $w_A = 0$). The innovator maximizes[21]

$$(1 - p_M - \tau_M - p_G - \tau_G)(y_C - w_A) + (p_M + \tau_M)(y_C - w_A)$$
$$+ (p_G + \tau_G)\theta_G(x_M - w)$$

subject to the R&D team's incentive constraint

$$-(\tau_G + \tau_M)w_A + \tau_M w_A + \tau_G \theta_G w \geq c. \tag{9}$$

It is optimal to set $w_A = 0$, implying that $\theta_G w = \frac{c}{\tau_G}$. Hence, the innovator's expected payoff is

$$(1 - p_M - \tau_M - p_G - \tau_G)y_C + (p_M + \tau_M)y_C + (p_G + \tau_G)\theta_G x_M - \frac{(p_G + \tau_G)}{\tau_G}c. \tag{10}$$

Private ownership and non-collusion at $t = 0.5$. The innovator takes the ex post efficient decision to continue the new technology after observing θ_M if $y_{NC} - w_A < \theta_M(x_M - w)$. This requires that $\theta_M x_M - y_{NC} > \theta_M w - w_A$. Suppose for now that this is satisfied (below we check when this is the case). The R&D team's incentive constraint is

$$-(\tau_G + \tau_M)w_A + (\tau_M \theta_M + \tau_G \theta_G)w \geq c. \tag{11}$$

It is optimal to set $w_A = 0$, implying that $w = \frac{c}{\tau_G \theta_G + \tau_M \theta_M}$, and the innovator's expected payoff is

$$(1 - p_M - \tau_M - p_G - \tau_G)y_{NC} + (p_M + \tau_M)\theta_M x_M \tag{12}$$
$$+ (p_G + \tau_G)\theta_G x_M - \frac{(p_G + \tau_G)\theta_G + (p_M + \tau_M)\theta_M}{\tau_G \theta_G + \tau_M \theta_M}c.$$

Continuation after observing θ_M requires

$$\theta_M x_M - y_{NC} > \theta_M w = \frac{\theta_M c}{\tau_G \theta_G + \tau_M \theta_M} \tag{13}$$

---

[21]Note that it is without loss that the R&D team is paid only in period one.

(i.e., y_{NC} is sufficiently low).

Suppose, next, that the inequality in (13) is not satisfied. Then the innovator does not have the right incentives at $t = 0.5$ to take the efficient continuation decision. This creates scope for renegotiations, in which the R&D team extracts γ of the additionally generated surplus. Denoting the R&D team's payoff in that case with w_R, we have

$$w_R = w_A + \gamma(\theta_M x_M - y_{NC}).$$

Hence, at the contracting stage $t = 0$, the R&D team's incentive constraint is

$$- (\tau_G + \tau_M) w_A + \tau_M (w_A + \gamma (\theta_M x_M - y_{NC})) + \tau_G \theta_G w \geq c. \tag{14}$$

It is optimal to set $w_A = 0$ and $w = \frac{c - \tau_M \gamma (\theta_M x_M - y_{NC})}{\tau_G \theta_G}$.[22] The innovator's expected payoff is

$$
\begin{aligned}
& (1 - p_M - \tau_M - p_G - \tau_G) y_{NC} + (p_M + \tau_M) (\theta_M x_M - \gamma (\theta_M x_M - y_{NC})) \\
& + (p_G + \tau_G) \left(\theta_G x_M - \theta_G \frac{c - \tau_M \gamma (\theta_M x_M - y_{NC})}{\tau_G \theta_G} \right) \\
= \; & (1 - p_M - \tau_M - p_G - \tau_G) y_{NC} + (p_M + \tau_M) \theta_M x_M \\
& + (p_G + \tau_G) \theta_G x_M + \gamma (\theta_M x_M - y_{NC}) \left(\frac{\tau_M}{\tau_G} p_G - p_M \right) - \frac{(p_G + \tau_G)}{\tau_G} c.
\end{aligned}
\tag{15}
$$

Subtracting now the innovator's payoff under non-collusion from that under collusion, we obtain

$$(1 - p_M - \tau_M - p_G - \tau_G) (y_C - y_{NC}) + (p_M + \tau_M) (y_C - \theta_M x_M) - c\theta_M \frac{\frac{\tau_M}{\tau_G} p_G - p_M}{\tau_G \theta_G + \tau_M \theta_M} \tag{16}$$

if there are no renegotiations under non-collusion, and

$$(1 - p_M - \tau_M - p_G - \tau_G) (y_C - y_{NC}) + (p_M + \tau_M) (y_C - \theta_M x_M) - \gamma (\theta_M x_M - y_{NC}) \left(\frac{\tau_M}{\tau_G} p_G - p_M \right) \tag{17}$$

if there are renegotiations. Hence, as long as $\frac{\tau_M}{\tau_G} p_G > p_M$, the R&D team's compensation is lower under non-collusion than under collusion, regardless of whether or not (13) is satisfied. Furthermore, both (16) and (17) decrease in p_M, p_G, and τ_M. Hence, there is

---

[22]Note that $\theta_B x_{FM} - \theta_B w$ is indeed negative (and renegotiations in $t = 0.5$ are needed) as

$$\theta_B x_{FM} - y_{NC} - \theta_B \frac{c - \gamma \tau_B (\theta_B x_{FM} - y_{NC})}{\tau \theta_G} = \left(1 + \theta_B \frac{\gamma \tau_B}{\tau \theta_G} \right) (\theta_B x_{FM} - y_{NC}) - \theta_B \frac{c}{\tau \theta_G} < 0.$$

a threshold $\widehat{p}_G$, such that not colluding is better for the innovator for all $p_G > \widehat{p}_G$. This threshold decreases (i.e., not colluding is more attractive) in τ_M, p_M, and x_M.

Finally, note that if $\theta_M x_M > y_C$, the continuation decision is the same under public and private ownership, and public ownership dominates. If $y_C > \theta_G x_M > y_{NC}$, public ownership dominates again, but the innovation is never undertaken under public ownership. **Q.E.D.**

Proof of Proposition 3. Observe, first, that the innovator's gross expected payoff is x_M if only it successfully develops the new technology, 0 if it is unsuccessful in developing the new technology, and y_O, if both firms successfully develop the new technology, where $O \in \{C, NC\}$ stands for whether or not the two firms collude. Given a probability θ_{Inc} of the incumbent also successfully developing the new technology, it is optimal for the innovator to abandon the new technology at $t = 0.5$ if $(1 - \theta_{Inc}) \theta x_{FM} + \theta_{Inc} \theta y_O < (1 - \theta_{Inc}) y_O$ or equivalently if

$$\theta x_{FM} + \frac{\theta_{Inc}}{1 - \theta_{Inc}} \theta y_O < y_O. \tag{18}$$

Hence, the abandonment threshold is higher than without competition. In particular, since $\frac{\theta_{Inc}}{1 - \theta_{Inc}}$ increases in θ_{Inc}, abandonment is optimal if and only if $\theta_{Inc} \leq \widehat{\theta}_{Inc} \equiv \frac{y_O - \theta x_{FM}}{y_O + \theta y_O - \theta x_{FM}}$, with $\widehat{\theta}_{Inc}$ increasing in y_O.

In what follows, we consider the case in which for θ_M, condition (18) holds for y_C, but not for y_{NC}, such that abandonment in state θ_M is optimal under public, but not under private ownership (in all other cases, public ownership dominates). We denote with w_{comp} the R&D team's wage in case both firms successfully develop the new technology.

Public ownership and collusion at $t = 0.5$. The R&D team's incentive constraint is

$$- (\tau_M + \tau_G) w_A + \tau_M w_A + \tau_G \theta_G ((1 - \theta_{Inc}) w + \theta_{Inc} w_{comp}) \geq c$$

It is optimal to set $w_A = 0$, implying that $\theta_G ((1 - \theta_{Inc}) w + \theta_{Inc} w_{comp}) = \frac{c}{\tau_G}$. Hence, the innovator's expected payoff is

$$(1 - p_M - \tau_M - p_G - \tau_G) (1 - \theta_{Inc}) y_C + (p_M + \tau_M) (1 - \theta_{Inc}) y_C$$
$$+ (p_G + \tau_G) ((1 - \theta_{Inc}) \theta_G x_M + \theta_{Inc} \theta_G y_C) - \frac{(p_G + \tau_G)}{\tau_G} c.$$

Private ownership and non-collusion at $t = 0.5$. Suppose, first, that the innovator takes the ex post efficient continuation decision without renegotiations (below we check

35

when this is the case). The R&D team's incentive constraint is

$$-\left(\tau_G + \tau_M\right)\left(1 - \theta_{Inc}\right)w_A + \left(\tau_G\theta_G + \tau_M\theta_M\right)\left(\left(1 - \theta_{Inc}\right)w + \theta_{Inc}w_{comp}\right) \geq c$$

It is optimal to set $w_A = 0$, implying that $\left(1 - \theta_{Inc}\right)w + \theta_{Inc}w_{comp} = \frac{c}{\tau_G\theta_G + \tau_M\theta_M}$, and the innovator's expected payoff is

$$\left(1 - p_M - \tau_M - p_G - \tau_G\right)\left(1 - \theta_{Inc}\right)y_{NC} + \left(p_M + \tau_M\right)\left(\left(1 - \theta_{Inc}\right)\theta_M x_M + \theta_{Inc}\theta_M y_{NC}\right)$$
$$+ \left(p_G + \tau_G\right)\left(\left(1 - \theta_{Inc}\right)\theta_G x_M + \theta_{Inc}\theta_G y_{NC}\right) - \frac{\left(\left(p_G + \tau_G\right)\theta_G + \left(p_M + \tau_M\right)\theta_M\right)}{\tau_G\theta_G + \tau_M\theta_M}c.$$

Continuation after observing θ_M requires that

$$\left(1 - \theta_{Inc}\right)\theta_M x_M + \theta_{Inc}\theta_M y_{NC} - \left(1 - \theta_{Inc}\right)y_{NC} > \frac{\theta_M c}{\tau_G\theta_G + \tau_M\theta_M}. \qquad (19)$$

Suppose, next, that the inequality in (19) is not satisfied. Then, the innovator does not have the right incentives at $t = 0.5$ to take the efficient decision to continue. This creates scope for renegotiations, in which the R&D team extracts γ of the additionally generated surplus $w_R := w_A + \gamma\left(\left(1 - \theta_{Inc}\right)\theta_M x_M + \theta_{Inc}\theta_M y_{NC} - \left(1 - \theta_{Inc}\right)y_{NC}\right)$. Hence, at the contracting stage $t = 0$, the R&D team's incentive constraint is

$$-\left(\tau_G + \tau_M\right)\left(1 - \theta_{Inc}\right)w_A + \tau_M w_R + \tau_G\left(\left(1 - \theta_{Inc}\right)\theta_G w + \theta_{Inc}\theta_G w_{comp}\right) \geq c$$

Hence, it is optimal to set $w_A = 0$ and $\left(1 - \theta_{Inc}\right)w + \theta_{Inc}w_{comp} = \frac{c - \tau_M w_R}{\tau_G\theta_G}$.[23] The innovator's expected payoff is

$$\left(1 - p_M - \tau_M - p_G - \tau_G\right)\left(1 - \theta_{Inc}\right)y_{NC} + \left(p_M + \tau_M\right)\left(\left(1 - \theta_{Inc}\right)\theta_M x_M + \theta_{Inc}\theta_M y_{NC}\right)$$
$$+ \left(p_G + \tau_G\right)\left(\left(1 - \theta_{Inc}\right)\theta_G x_M + \theta_{Inc}\theta_G y_{NC}\right) + \left(\frac{\tau_M}{\tau_G}p_G - p_M\right)w_R - \frac{\left(p_G + \tau_G\right)}{\tau_G}c.$$

Subtracting the innovator's payoff under non-collusion from that under collusion, we

[23]It is straightforward to verify that for this wage, there are, indeed, renegotiations at $t = 0.5$.

obtain

$$
\begin{aligned}
&\left(1 - p_M - \tau_M - p_G - \tau_G\right)\left(1 - \theta_{Inc}\right)\left(y_C - y_{NC}\right) \\
&+ \left(p_M + \tau_M\right)\left(\left(1 - \theta_{Inc}\right) y_C - \left(1 - \theta_{Inc}\right)\theta_B x_M - \theta_{Inc}\theta_B y_{NC}\right) \\
&+ \left(p_G + \tau_G\right)\theta_{Inc}\theta_G\left(y_C - y_{NC}\right) - c\theta_B \frac{\frac{\tau_M}{\tau_G} p_G - p_M}{\tau_G\theta_G + \tau_M\theta_B}
\end{aligned} \tag{20}
$$

if there are no renegotiations under non-collusion, and

$$
\begin{aligned}
&\left(1 - p_M - \tau_M - p_G - \tau_G\right)\left(1 - \theta_{Inc}\right)\left(y_C - y_{NC}\right) \\
&+ \left(p_M + \tau_M\right)\left(\left(1 - \theta_{Inc}\right) y_C - \left(1 - \theta_{Inc}\right)\theta_B x_M - \theta_{Inc}\theta_B y_{NC}\right) \\
&+ \left(p_G + \tau_G\right)\theta_{Inc}\theta_G\left(y_C - y_{NC}\right) - \left(\frac{\tau_M}{\tau_G} p_G - p_M\right) w_R
\end{aligned} \tag{21}
$$

if there are renegotiations.

Let $\widehat{p}'_G\left(\theta_{Inc}\right)$ define the value for p_G at which (20) and, respectively, (21) is zero. To see when such a point exists, note that both (20) and (21) are positive for $p_G = \theta_{Inc} = 0$, implying that public ownership dominates for these parameter values. Furthermore, taking the partial of (20) with respect to p_G we have

$$
-\left(1 - \theta_{Inc}\right)\left(y_C - y_{NC}\right) + \theta_{Inc}\theta_G\left(y_C - y_{NC}\right) - c\theta_B \frac{\frac{\tau_M}{\tau_G}}{\tau_G\theta_G + \tau_M\theta_B}
$$

and, respectively, of and (21) with respect to p_G

$$
-\left(1 - \theta_{Inc}\right)\left(y_C - y_{NC}\right) + \theta_{Inc}\theta_G\left(y_C - y_{NC}\right) - \frac{\tau_M}{\tau_G}\gamma\left(\left(1 - \theta_{Inc}\right)\theta_B x_M + \theta_{Inc}\theta_B y_{NC} - \left(1 - \theta_{Inc}\right) y_{NC}\right).
$$

Both of these partials are negative when evaluated at $\theta_{Inc} = 0$, implying that the attractiveness of public ownership decreases when p_G increases just as in Proposition 2. Finally, (20) and (21) are negative for $p_G = 1 - \tau_G$ (i.e., $p_M = \tau_M = 0$). Thus, when $\theta_{Inc} = 0$, there is a unique point $\widehat{p}'_G\left(\theta_{Inc}\right)$, such that the innovator prefers public private ownership if an only if $p_G > \widehat{p}'_G\left(\theta_{Inc}\right)$. Clearly, this point corresponds to $\widehat{p}_G$ Proposition 2.

To analyze the effects as θ_{Inc} increases beyond zero, recall that public ownership always dominates for $\theta_{Inc} \geq \widehat{\theta}_{Inc}$ (as defined in the beginning of the proof). Furthermore, taking the cross-partial of (20) with respect to p_G and θ_{Inc}, we obtain

$$
\left(y_C - y_{NC}\right) + \theta_G\left(y_C - y_{NC}\right) > 0. \tag{22}
$$

The positive sign of (22) implies that the increase in attractiveness of private ownership

for higher values of p_G is weaker for higher values of θ_{Inc}, implying that a value $\widehat{p}'_G(\theta_{Inc})$ for which (20) is zero is less likely to exist for higher θ_{Inc}.

The same insight obtains if the cross partial of (21) with respect to p_G and θ_{Inc}

$$(y_C - y_{NC}) + \theta_G (y_C - y_{NC}) + \frac{\tau_M}{\tau_G} \gamma (\theta_B x_M - (1 + \theta_B) y_{NC}), \tag{23}$$

is positive. However, if (23) is negative, $\widehat{p}'_G(\theta_{Inc})$ is guaranteed to exist even for higher values of θ_{Inc} as long as $\theta_{Inc} < \widehat{\theta}_{Inc}$. **Q.E.D.**

Proof of Corollary 1. If p_G is very low, neither firm starts the new technology's development and public ownership dominates. If p_G is very high, both firms start the new technology's development and never abandon it (see (18)). The interesting case is when p_G is high enough that the innovator starts developing the new technology, but that this technology is abandoned if the innovator observes θ_B under private, but not under public ownership. The difference in payoffs between public and private ownership is a convex function of p_G. To see this, use that $\frac{\partial \theta_{Inc}}{\partial p_G} = \theta_G$ and take the second derivative of (20) with respect to p_G to obtain

$$2\theta_G (\theta_G + 1) (y_C - y_{NC}).$$

The second derivative of (21) with respect to p_G is

$$2\theta_G \left((\theta_G + 1) (y_C - y_{NC}) + \gamma \frac{\tau_M}{\tau_G} (\theta_B x_M - (\theta_B + 1) y_{NC}) \right),$$

which is also positive. Thus, the attractiveness of public ownership is a convex function of p_G. Together, all of this implies a U-shaped relationship between p_G and the attractiveness of public ownership. **Q.E.D.**

Proof of Proposition 4. Suppose that both firms adopt the same technology in periods one and two and that Assumption 2 is not satisfied for the incumbent. Since $2x_C - bx_{NC} > K$ and $x_C - m > x_{NC}$, playing C in both periods is a dominant strategy for the incumbent regardless of the action taken by the innovator.

To see that it may be optimal to remain small if b is sufficiently large, note that there are four cases to consider: The innovator is public and innovates alone; it is private and innovates alone; it is private and competes with the incumbent on innovation; it is public and competes with the incumbent on innovation. The relevant case depends on the parameter constellations,

In the first case, the innovator abandons the new technology following signal θ_B regardless of whether it is large or small. Hence, the cost of motivating the R&D team is the same, and remaining small is preferable (cf. 10) if

$$(1 - p_M - \tau_M - p_G - \tau_G) \, b y_{NC} + (p_M + \tau_M) \, b y_{NC} + (p_G + \tau_G) \, \theta_G x_M - \frac{(p_G + \tau_G)}{\tau_G} c$$

$$> \quad (1 - p_M - \tau_M - p_G - \tau_G) \, \varphi y_C + (p_M + \tau_M) \, \varphi y_C + (p_G + \tau_G) \, \theta_G \varphi x_{FM} - \frac{(p_G + \tau_G)}{\tau_G} c \tag{24}$$

For this case, the threshold $b_1(\varphi)$ is defined by

$$b > b_1(\varphi) \equiv \varphi \frac{y_C}{y_{NC}} + \frac{(p_G + \tau_G) \, \theta_G \, (\varphi - 1) \, x_{FM}}{(1 - p_G - \tau_G) \, y_{NC}}$$

We omit the argument for the remaining three cases, as it is analogous. **Q.E.D.**

Proof of Proposition 5. (i) Let θ_{Inc}^{Innov} be the likelihood that the innovator successfully develops the new technology. Furthermore, let V^{Inc} be the incumbent's expected payoff when starting the new technology's development, and $V^{Innov,no\ comp}$ and $V^{Innov,comp}$ be the innovator's expected payoffs depending on whether it is competing with the incumbent for the new technology. The incumbent starts the new technology's development if

$$V^{Inc} + \beta V^{Inov,comp} - k \geq \left(1 - \theta_{Inc}^{Innov}\right) y_C + \beta V^{Innov,no\ comp} \tag{25}$$

Differentiating both sides of (25) with respect to β, $V^{Innov,no\ comp} > V^{Inov,comp}$ implies that increasing β, makes condition (25) more difficult to satisfy.

(ii) If the incumbent firm buys a controlling stake in the innovator, it dictates that the innovator continues the new technology also if the signal realization is θ_B. This is because the incumbent is guaranteed the monopoly profit on the incumbent technology if the new one fails, so it faces no opportunity cost from continuation. Hence, motivating the R&D team requires satisfying the incentive constraint

$$- (\tau_G + \tau_M) \, w_A + (\tau_M \theta_B + \tau_G \theta_G) \, w \geq c.$$

As shown in Proposition 2, this leads to a lower compensation cost than if the new technology is abandoned in case of θ_B if $\frac{\tau_M}{\tau_G} p_G > p_M$. Moreover, absent competition, the incumbent's profit in case of success is higher, increasing the likelihood that the new technology's development is initiated. **Q.E.D.**

Appendix B: Public Ownership and Antitrust Lawsuits

In what follows, we present patterns in the data that are consistent with our predictions that public ownership may facilitate collusion and that there is a U-shaped relation between the attractiveness of innovation and the benefit of public ownership. We construct a sample of firms that have filed an initial registration statement for an IPO with the SEC (Form S-1) and then compare firms that have gone through with their IPO to firms that have chosen to withdraw their IPO filing (by submitting Form RW). The data on U.S. IPO filings and withdrawals comes from Thomson One's New Issues database from 1985 until 2017. As it is standard, we exclude financial firms (SIC codes 6000-6999), unit offers, closed-end funds, American depositary receipts, limited partnerships, special acquisition vehicles, and spin-offs. Financial information comes from Compustat, Thomson One, and from the S-1 filing forms. We have such data for approximately 70% of the firms.[24]

INSERT TABLE 1

To proxy for collusion, we collect all U.S. lawsuits related to antitrust or anticompetitive behavior from Thomson Reuters' Westlaw database for the period 1990-2017.[25] We then manually match the defendants in these lawsuits to our IPO filings sample. Note that this focuses on illegal collusion, which is only a small subset of the coordination possibilities we have in mind. However, this could still be indicative for the wider collusion possibilities that public ownership facilitates. To allow for a four-year post-filing window, we restrict attention to IPOs between 1994–2013. In this period we have 4762 IPO filings, 22% of which were withdrawn. We have matched 308 of the filing firms to antitrust cases between 1990–2017.

Table 1 offers summary statistics comparing the firms going through with their IPOs and those withdrawing their filings within four years of their S-1 filing. The two groups are similar in terms of size and sales, but those that withdraw are slightly less profitable. The key notable difference is that the likelihood of being involved in an antitrust lawsuit in the four years surrounding the filing is insignificantly different before and after the filing for firms that withdraw, but increases threefold for firms that proceed with the IPO. It is also notable that withdrawals are associated with significantly lower two-month NASDAQ returns following the filing, while there is no difference in the pre-filing returns.

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[24]We thank Tolga Caskurlu for providing us with the financials of firms that withdraw their IPOs, which was manually extracted from the S-1 filings.

[25]The coverage of this database for lawsuits prior to 1990 is sparse.

6.0.1 Empirical Challenges and Limitations

Testing our model's predictions faces two main empirical challenges. The first is finding comparable public and private firms. Comparing firms that complete to firms that withdraw their IPO has the advantage of comparing public to private firms at similar stages of their lifecycle. However, the decision to withdraw is still highly endogenous and ideally would need to be controlled for. One possibility is to follow Bernstein (2015) who proposes to instrument IPO withdrawal with the NASDAQ two-months ahead return following the IPO filing. The idea is that negative fluctuations in NASDAQ in the two months following the filing could drive firms to withdraw their filings for reasons that are orthogonal to how their fundamentals predispose them to collude.[26]

The second challenge is finding evidence for collusive behavior. Antitrust lawsuits are an imperfect proxy that restricts attention to outright illegal avoidance of competition. Ideally, we would like to test also for coordination of strategy that facilitates the avoidance of competition and is not considered illegal. The higher transparency of public ownership also raises the concern that regulators may be better able to detect antitrust behavior. Another concern is that being cash-rich after an IPO could attract frivolous lawsuits that only aim for a settlement.

Because of these concerns, we emphasize that the evidence we present in what follows is mainly meant to serve as a motivation for further more rigorous analysis about the relation between competition avoidance and public ownership.

Nevertheless, it should be stressed that there are serious concerns also regarding the above-mentioned alternative explanations. Detecting anticompetitive behavior mainly relies on leniency provision for whistle blowers. Even though economic analysis can be instrumental in prosecuting antitrust cases and estimating damages, it has not been a standard tool for detecting cartels (Harrington, 2008).[27] When it is used, it typically relies on micro industry data about costs, prices, and quantities (Viscusi et al., 2005). In any case, as part of their S-1 filing, all firms in our sample (including those that withdraw) must publish historical audited financial statements, interim unaudited statements, as well as a "Management's Discussion and Analysis" section that describes future trends and competition. Thus, if financial statements help better detection, then antitrust lawsuits should increase for *all* firms in our sample in the year following the filing (but we show below

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[26]Reasons why firms do not wait for conditions to improve is that a filing registration automatically expires 270 days after its last amendment. Furthermore, firms are forbidden from issuing private placements while their application is pending as well as from disclosing new information to specific investors, such as banks. See Bernstein (2015) for details.

[27]In the U.S., economic evidence is typically not sufficient for proving guilt, and there must be some evidence of coordination (Werden, 2004).

that this is not the case). What is also notable is that more than 90% of the cases in our sample were brought by businesses or individuals (rather than the FTC, the DOJ, or state attorney generals) that must demonstrate an antitrust injury that is "inextricably intertwined" with the alleged conduct.

Furthermore, it is not clear that frivolous lawsuits are necessarily directed towards cash-rich firms. In fact, the law literature has discussed that such lawsuits are often targeted at cash-strapped firms that would rather avoid costly litigation; and such lawsuits could be of anticompetitive nature themselves (Meurer, 2003). What speaks against the frivolous lawsuits argument is that there is *no* increase in lawsuits in the first two years after the IPO. The effects (we document below) only emerge in the third year, and are strongest in the fourth and fifth years. This is consistent with public firms needing time to start colluding and inconsistent with plaintiffs initiating opportunistic antitrust lawsuits against newly-public firms.

6.0.2 Results

The first tests we present look at the determinants of whether an IPO proceeds

$$
\begin{aligned}
IPO_i \quad = \quad & \alpha + \beta_1 \Delta Industry\ R\&D + \beta_2 \Delta Industry\ R\&D^2 + \beta_3 Industry\ R\&D + \beta_4 Industry\ R\&D^2 \\
& + \gamma NASDAQ_i + \delta X_i + \nu_k + \mu_t + \varepsilon_i,
\end{aligned}
\tag{26}
$$

and the second set of tests look at the determinants of whether there is an antitrust lawsuit after the IPO filing

$$
\begin{aligned}
AT_i^{post} \quad = \quad & \alpha + \beta_1 \Delta Industry\ R\&D + \beta_2 \Delta Industry\ R\&D^2 + \beta_3 Industry\ R\&D + \beta_4 Industry\ R\&D^2 \\
& + \gamma IPO_i + \delta X_i + \nu_k + \mu_t + \varepsilon_i,
\end{aligned}
\tag{27}
$$

where AT_i^{post} is a binary variable taking the value of one if the firm is involved in an antitrust lawsuit in the four years after the IPO filing; IPO_i takes the value of one if the firm goes through with its IPO; *Industry R&D* are the average industry R&D expenses relative to total assets at two digit SIC level, $\Delta Industry\ R\&D$ is the change in such expenses relative to the pre-filing year. These variables proxy for the attractiveness of innovation in the industry. The quadratic specifications considers non-linear effects, where the U-shaped prediction implies that β_1 and β_3 in equation (26) should be negative, while β_2 and β_4 positive. The control variables X account for whether there was an antitrust lawsuits in the four years prior to the IPO filing (AT_i^{pre}), size (*Log total assets*, adjusted to inflation), revenues (*Sales/assets*), profitability (*Net income/assets*). The regressions further contain industry fixed effects at the two digit SIC level and IPO filing year fixed

effects.

Columns (1) and (2) of Table 2 show the estimates of an OLS and a probit model of the determinants that an IPO proceeds. In these two models, the quadratic specifications of the change in R&D spending, $\Delta Industry\ R\&D$, is significant, indicating a convex (i.e., U-shaped) relation between the likelihood of completing the IPO and the attractiveness of innovation. Figure 2 in the Appendix plots this relation, which is consistent with Implications 5-6. The levels of $Industry\ R\&D$ spending convey a similar, but a statistically weaker, relation.[28]

<center>INSERT TABLE 2</center>

Column (3) in Table 2 shows a strong positive association between antitrust lawsuits in the four years after the IPO filing and whether the firm proceeds with its IPO. Such lawsuits increase by two percent, which is more than double the unconditional likelihood of being involved in such a lawsuit. This finding is consistent with Implication 1 that public ownership facilitates collusion.

As noted in Section 6.0.1, though it is hard to deal with the problem that antitrust lawsuits are an imperfect proxy for collusion, we can address to some extent the problem that the decision to withdraw an IPO can be related to unobserved factors related to antitrust lawsuits. Specifically, using model (1) in Table 2, we can instrument IPO completion using $NASDAQ$ returns in the two months since the start of the book-building phase and use the predicted values of IPO from regression (26). The second-stage estimation results are presented in column (4) in Table 2. To account for the fact that IPO is a binary variable, we can further follow the three-stage procedure outlined in Wooldridge (2002, p. 623, procedure 18.1). In the first stage, we estimate a probit of the determinants that an IPO proceeds (column (2) in Table 2). In the second stage, we regress IPO on the fitted values from the first stage, the industry R&D variables, and X. In the third stage, we regress Y_i^{post} on the fitted values from the second stage, the industry R&D variables, and X.[29] Note that the coefficients estimates in columns (4) and (5) are determined only from the firms that would change their IPO decision due to a shift in NASDAQ, and therefore are sensitive to such shifts (Imbens and Angrist, 1994).

Columns (1) and (2) in Table 2 show that fluctuations in the NASDAQ in the two moths after the IPO filing strongly affect the likelihood of withdrawal. Table 3 shows that it is unlikely that antitrust lawsuits depend on stock market movements in general other

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[28]The significance is higher if the regressions are run without $\Delta Industry\ R\&D$. The results are also robust to using industry averages weighted by total assets or sales.

[29]For an explanation of the procedure, see also Adams et al. (2009).

than over the IPO continuation decision. Specifically, we show that one-year NASDAQ returns both in the years before and after the IPO filing are uncorrelated with whether there is an antitrust lawsuit four years after the filing. Hence, $NASDAQ$ appears to be a valid instrument for the likelihood that the IPO is completed. Supportive of this claim is also that the F-statistic of the first stage of the 2-SLS has a value of 25.

The results from models (4) and (5) show a strong impact of the instrumented IPO variable on the likelihood of an antitrust lawsuit. The coefficients state that the likelihood of being involved in an antitrust lawsuit increases by about 10%, which is not only statistically, but also economically significant given that the unconditional likelihood of such a lawsuit for firms that withdraw their IPOs is 1%

Overall, to the extent that we could make inferences from antitrust lawsuits about collusion, the empirical patterns we present are consistent with Implication 1 that public ownership helps facilitate collusion and of Implications 5–6 that there is a U-shaped relation between the attractiveness of innovation and that of public ownership.

Table 1: **Summary Statistics.** This table compares the sample of firms that complete their IPO filings with the sample of firms that withdraws their filings. *AT case after/before filing* is a dummy variable equal to one if there is an antitrust case in the four years after/before the filing. *Postfiling NASDAQ returns* are the two months NASDAQ returns following the IPO filing, *Prefiling NASDAQ returns* are the three month return prior to the filing, *Total assets* are the total assets, adjusted to inflation (base year 1999), *Net income/assets* and *Sales/assets* are the ratios of net income and sales to total assets, winsorized at one percent, *Industry R&D* is the average R&D spending over total assets, weighted by total assets, for the respective industry in a given year. Industry is defined at the two-digit SIC level. *, **, and *** indicate that the differences in means are statistically significant at the 10%, 5%, and 1% level, respectively.

	Completed			Withdrawn			
	Mean	Median	SD	Mean	Median	SD	Difference
AT case before IPO filing	0.006	0.000	0.079	0.004	0.000	0.066	0.002
AT case after IPO filing	0.020	0.000	0.141	0.006	0.000	0.078	0.014***
Total asssets	180.996	28.900	801.909	164.678	22.273	736.947	16.318
Net income/assets	-0.265	-0.044	0.692	-0.375	-0.061	0.917	0.11***
Sales/assets	1.074	0.818	1.099	1.186	0.729	1.356	-0.112***
Industry R&D	0.033	0.043	0.025	0.032	0.042	0.025	0.001
Postfiling NASDAQ returns	0.025	0.031	0.098	-0.018	-0.004	0.121	0.043***
Prefiling NASDAQ returns	0.058	0.051	0.115	0.051	0.041	0.139	0.007

Table 2: **Going Public and Antitrust Lawsuits.** This table reports the effect of an IPO on the likelihood of an antitrust lawsuit in the four years after the IPO filing. In models (1) and (2), the dependent variable is IPO, which is a dummy variable, equal to one if the firm does not withdraw its IPO. Model (1) presents the estimates from an OLS, while model (2) the estimates from a probit regression. In models (3)–(5), the dependent variable is $AT\ case\ after\ filing$, which is a dummy variable equal to one if there is an antitrust case in the four years after the filing. Model (3) shows OLS estimates. Model (4) presents the second stage of the 2SLS estimates, and model (5) presents the third stage of Wooldridge's three-stage procedure (18.1). The latter two models are described in Appendix B. Variable definitions are as in Table 1. All regressions include filing year and industry fixed effects at the two digit SIC level. Robust t-statistics are reported in the parantheses. *, **, and *** indicate that the coefficient is statistically significant at the 10%, 5%, and 1% level, respectively.

	(1)	(2)	(3)	(4)	(5)
			AT case	AT case	AT case
Dependent variable	IPO	IPO	after filing	after filing	after filing
IPO			0.021***	0.139**	0.083***
			(3.992)	(2.255)	(2.664)
NASDAQ returns	0.406***	1.414***			
	(5.433)	(5.460)			
ΔIndustry R&D	-0.120***	-0.480***	0.015	0.029	0.024
	(-2.819)	(-2.656)	(0.859)	(1.559)	(1.324)
ΔIndustry R&D^2	0.026***	0.106**	-0.003	-0.006	-0.005
	(2.706)	(2.512)	(-0.769)	(-1.453)	(-1.216)
Industry R&D	-1.726	-7.463**	-0.786*	-0.582	-0.723*
	(-1.625)	(-1.970)	(-1.867)	(-1.328)	(-1.730)
Industry R&D^2	1.640	9.670	1.129	0.939	1.105
	(0.702)	(1.176)	(1.437)	(1.147)	(1.400)
AT case before filing	-0.023	-0.051	0.224***	0.227***	0.234***
	(-0.304)	(-0.150)	(2.623)	(2.632)	(2.650)
Log total assets	0.042***	0.163***	0.009***	0.004	0.007***
	(8.394)	(8.655)	(4.436)	(1.356)	(3.151)
Net income/assets	-0.012	-0.050	-0.009***	-0.008**	-0.008***
	(-0.898)	(-1.208)	(-3.149)	(-2.336)	(-2.792)
Sales/assets	-0.017**	-0.069***	0.002	0.004	0.003
	(-2.161)	(-2.668)	(0.645)	(1.245)	(1.018)
Constant	0.221**	1.427***	0.034	-0.105	-0.052
	(2.390)	(3.890)	(0.674)	(-1.598)	(-1.181)
Filing year FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Observations	3486	3432	3486	3486	3432
R^2	0.173		0.069	.	0.043
Pseudo R^2		0.180			

Table 3: **NASDAQ Drops and Placebo Test**. Panel A of this table compares firms that experience a two month post filing Nasdaq return in the bottom 10% and top 90% of the filing year, and the bottom 25% and top 75%, respectively. Variable definitions are as in Table 1. Panel B reports placebo tests for the validity of the instrumental variable exclusion restriction. The dependent variable is $AT\ case\ after\ filing$ that takes the value of one if there was an antitrust case in the four years after the IPO filing. $Nasdaq\ returns$ is defined as in Table 1. $Nasdaq\ 1\ year\ post/pre\ filing$ are defined as the NASDAQ one-year return following/preceding the IPO filing. The models are estimated using OLS, and robust t-statistics are presented in parantheses. *, **, and *** indicate that the coefficient is statistically significant at the 10%, 5%, and 1% level, respectively.

Panel A: NASDAQ Drops and Firm Characteristics	(1) Bottom 10%	(2) Top 90%	(3) Difference	(4) Botton 25%	(5) Top 75%	(6) Difference
AT case before IPO filing	0.000	0.006	-0.006*	0.007	0.006	0.001
AT case after IPO filing	0.015	0.026	-0.011	0.015	0.023	-0.008*
Total asssets	124.980	113.320	11.660	208.715	176.806	31.909
Net income/assets	-0.317	-0.317	0.000	-0.283	-0.313	0.030
Sales/assets	1.162	1.057	0.105	1.125	1.060	0.065
Industry R&D	0.035	0.034	0.001	0.033	0.032	0.001

| Panel B: Placebo test	(1)	(2)	(3)	(4)	(5)
Dependent variable	AT case after filing	AT case after filing	AT case after filing	AT case after filing	AT case after filing
NASDAQ returns	0.058**			0.057**	0.056**
	(2.451)			(2.510)	(2.390)
NASDAQ 1 year post filing		-0.008		0	
		(-0.447)		(-0.007)	
NASDAQ 1 year pre filing			0.009		0.005
			(1.019)		(0.563)
Control variables	Yes	Yes	Yes	Yes	Yes
Filing year FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Observations	3486	3486	3486	3486	3486
R^2	0.052	0.051	0.051	0.052	0.052
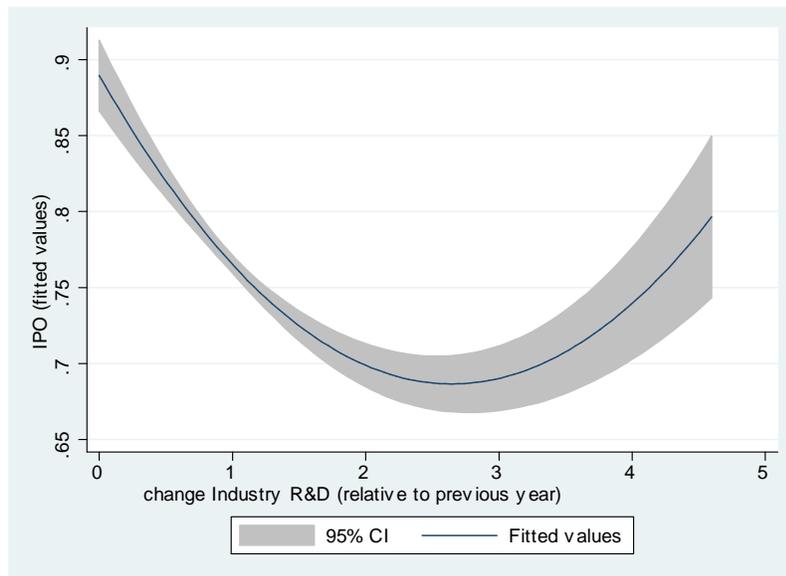
Figure 2: **Quadraticly fitted relation between IPO and ΔIndustry R&D.** The figure plots the fitted values of IPO from model (1) in Table 2 against $\Delta Industry\ R\&D$, which is the change in average R&D spending to total assets in the same two-digit SIC industry in the IPO filing year relative to the previous year. The gray area presents the 95% confidence interval.