# Collusion with Public and Private Ownership and Innovation

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May 19, 2018

**Abstract**

We argue that public ownership helps firms avoid head-to-head competition. However, collusion opportunities on existing technologies reduce the commitment to develop new ones, and could destroy firm value. We show that the latter effect dominates when a new technology's expected profitability is intermediate, in which case private ownership is optimal. Opportunities to avoid competition increase firm value when new technologies appear either only marginally or very attractive, resulting in a U-shaped relation between the attractiveness of innovation and public ownership. While buying equity stakes also reduces competition, it is an imperfect substitute. Our main predictions are consistent with empirical patterns and shed light on several puzzling stylized facts.

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

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# 1 Introduction

The demise of the public corporation as evidenced by the decline of 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 imposes costs and could lead to leaking of valuable information to competitors (Bhattacharya and Ritter, 1984). Despite such arguments and gloomy projections, public firms, including companies vulnerable to sharing sensitive information such as firms in the biotech and pharma sectors, are profitable like never before.[1] Adding to the contradictions surrounding the effects of going public, recent empirical work has documented that the quality of internal innovation declines following an IPO (Bernstein, 2015). Yet, simultaneously, public firms, such as Amazon, Apple, and IBM, are at the forefront of innovation and aggressively pursue long-shot game-changing technologies. For example, 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. The collusion opportunities we have in mind are not limited to price and quantity fixing, but also include opportunities to *avoid* competing with each other. What may facilitate such avoidance is reporting on investments, new products and services, large customers, break down of cash flows according to geographical presence and business segments, and lawsuits with competitors and business partners.[3]

By affecting the margins on existing services and products, opportunities to avoid head-to-head competition have an impact on firms' incentives to innovate. One of our main results is 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 are likely to abandon innovation

[1] As of May 2018, the annualized returns of the S&P 500 Biotechnology and Pharma Select Industry Indexes over the last ten years were 17% and 13%, respectively. See also "Larry Summers: Corporate profits are near record highs. Here's why that's a problem," Washington Post, March 30, 2016.

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

[3] The conflict between the calls for more transparency in public firms and antitrust concerns has been recognized in the law literature (Steuer et al., 2011) and features in the OECD Competition Committee (2012) roundtable discussions.

and benefit from colluding on old technologies (i.e., low attractiveness of innovation) or very likely to stick to pursuing innovation and benefit from colluding on the new technologies (high attractiveness of innovation). For innovation in the middle spectrum, private ownership dominates. Its benefit is that it helps the firm commit not to abandon the new technology in the face of early difficulties, as private ownership makes it harder to collude on old technologies. These insights are consistent with the above contradictory evidence as well as with evidence from antitrust lawsuits 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 engage in 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 when both firms use the same technology, 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 facilitating 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.

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

The option to collude on the existing technology improves its profitability and, hence, can be beneficial for the firm. However, it also makes it more likely that the innovator abandons the development of the new technology in the face of a 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 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 becomes sufficiently high. Then, the option to collude on the existing technology associated with public ownership becomes relatively 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.

We extend the model along several dimensions. First, we analyze taking equity stakes as an alternative way to achieve collusion. When buying an equity stake in the innovator, the incumbent's own innovation incentives are reduced, and completely vanish if the stake is a controlling one. Yet the overall effect on innovation is ambiguous, as the innovator innovates more when not having to compete against the incumbent. Second, we analyze the effect of the relative sizes of the incumbent and innovator. A relatively small innovator might choose to stay out of the collusive strategies of its larger competitors and chip away market share without triggering a response. This could create incentives to stay small and would reduce innovation incentives. Third, we show that voluntary reporting by private firms does not help much to achieve collusion, as absent exogenous strict reporting requirements, private firms will have incentives to add noise to their reporting, making collusion not sustainable.

We provide some tentative empirical support for the notion that being public facilitates collusion. Comparing firms that file for an IPO and persist in becoming public with firms that file for an IPO, but subsequently withdraw their filing, we find that the likelihood of being involved in an antitrust lawsuit is more than two times higher for firms that complete their IPO. While far from conclusive, this evidence is consistent with the claim that public ownership facilitates collusion.[4] We further find evidence for the U-shaped relation between the attractiveness of innovation and that of public ownership.

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, 1984; 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.

In line with our view 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). Furthermore, 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 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 with private financing helps early investors to exit. In their model, the lack of transparency associated with private ownership prevents outside investors from inferring whether the true reason for exit is an illiquidity shock or that the firm's innovation has failed. Somewhat reminiscent of Grossman and Stiglitz's (1980) information efficiency paradox, this noise makes it less costly for investors to exit, making early private investors ex ante more willing to invest in risky innovations. Contrary to our analysis, there are no time inconsistency prob-

[4] Note that our insights on how being public facilitates the avoidance of competition stretch beyond the outright illegal cases involving antitrust violations.

lems 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. By contrast, we show that, new ideas are better explored under public ownership if they are expected to be either very profitable or only marginally profitable. Private ownership dominates only for intermediate values for the new technology's profitability.[5] Furthermore, we discuss the effect of equity stakes and the relative sizes of the firms involved for the ability to collude and how that affects innovation and the public-private choice. These different perspectives generate an interesting contrast in empirical predictions.

The U-shaped relationship between the attractiveness of public ownership and the new technology's profitability is also the main difference with the managerial myopia literature in which public ownership creates time inconsistency due to a manager's focus on the current stock price (Stein, 1989). In our model, the reason for time inconsistency 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. A further difference is that in our model the ability to collude under public ownership is also valuable when firms compete to develop the new technology, as then they could collude not to eat into each other's profits once both have successfully developed the new technology.

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 paper is that we are interested in how the interplay between collusion opportunities and innovation interacts with the choice between public and private ownership.[7] We show that such interactions could shed light on explain stylized facts, including why the recent

[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 (2016) 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 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.

[7] We also focus on equity stakes as a coordination device. Prior work shows that cross-ownership could reduce incentives to compete (Reynolds and Snapp, 1986) as well as reduce innovation incentives (Matthews, 2006), but could also sometimes make collusion more difficult (Malueg, 1992). Related is also the literature linking the going public decision to product market competition absent collusion (Chod and Lyandres, 2010).

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 new technology is risky. The innovator can make it work with probability $\theta$, in which case it generates positive cash flows. With probability $1 - \theta$, the innovator is unable to develop the new technology and cannot generate any cash flows. The probability $\theta$ 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 $\theta_M$ and $\theta_G$ 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 $\theta_M$ and $\theta_G$ 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 $\theta_M$ and $\theta_G$ 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 $\theta$. 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 or not to abandon the new technology lies with the innovator, and not the R&D team.[8]

[8] 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.

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, and would succeed in developing it with probability $\theta_{Inc}$, with no additional information about $\theta_{Inc}$ revealed at $t = 0.5$.[9]

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 $x_{FM}$ ($\frac{x_{FM}}{2}$ 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.

**Coordination Problem if Both Firms Use the Same Technology** What do we mean by collusion and how does it work? Collusion may refer to avoiding competition on price and quantity when offering identical products or services. However, as emphasized in the introduction, it can also mean more broadly any action (or lack of action) that helps avoid head-to-head competition. An example illustrating the latter is when firms allow each other to pursue distinct strategies even if there are no technological hurdles to mimic each other's strategies.[10] We model this by stipulating that, in each period when using the same technology, both firms decide whether to collude (action $C$) or not collude (action $NC$). The action 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 preferred (and available) technology in that period are $x_C$ for each. If neither firm colludes, their expected cash flows are $x_{NC} < x_C$. 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 $b > 1$.

A feature of the model is that in a one-shot game (single period) both firms face a prisoner's dilemma, making collusion over one period impossible. However, collusion is potentially possible in a two period setting. To facilitate this, we assume that firms face a (one-time) cost $K$ the first time they seek collusion, but no such cost in the following

[9] We want to capture the situation where the incumbent may not want to pursue all innovation opportunities that the innovator pursues. The deadweight cost $k$ of diverting resources guarantees this.

[10] A large strand of the industrial organization literature analyzes collusion when firms' products are not perfect substitutes (e.g., Chang, 1991; Ross, 1992).

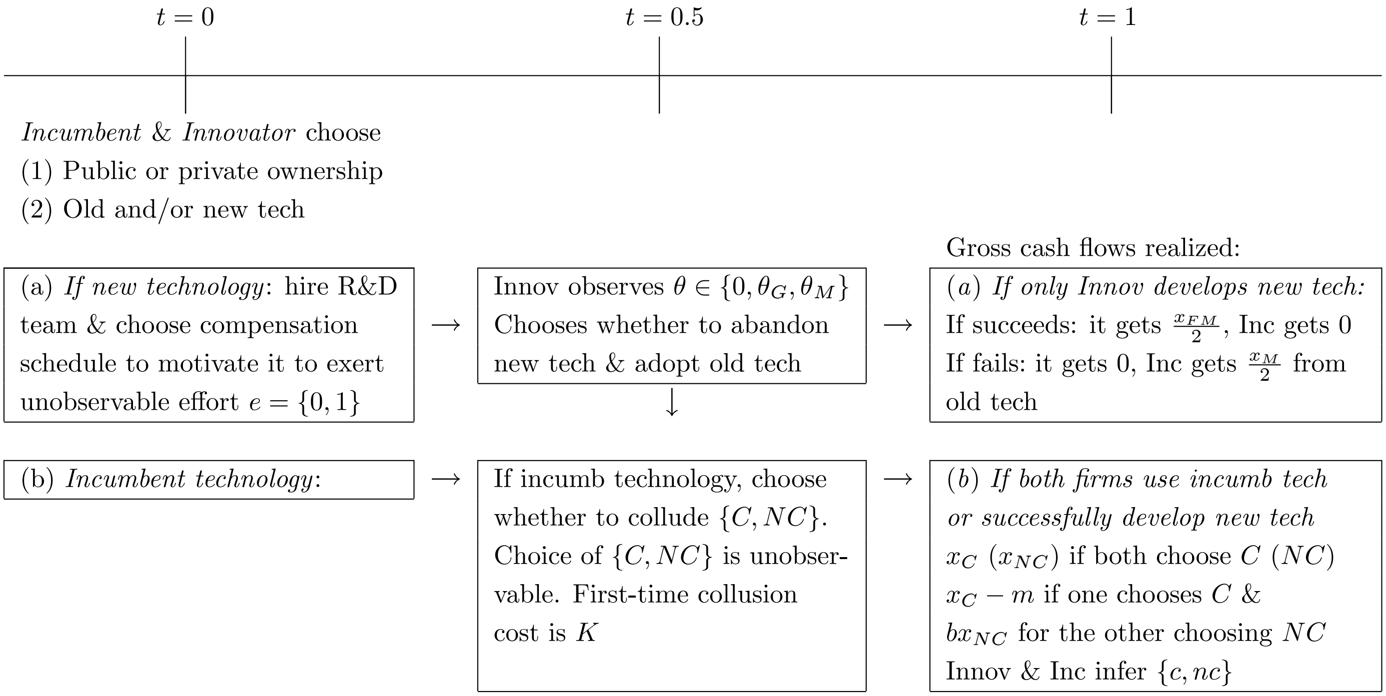


Figure 1: **Timeline of first period.**

period. We now let $x_C - K < bx_{NC}$. This means that in a one-period setting, the prisoner's dilemma is acute: anticipating collusion by the other firm, makes choosing no collusion optimal. However, if collusion is chosen nonetheless, colluding again in the following period yields $x_C > bx_{NC}$. Assuming in addition that $(x_C - K) + x_C > bx_{NC} + x_{NC}$ makes collusion over two periods potentially worth it. Summarizing:

**Assumption 1**: $2x_C - (bx_C + x_{NC}) > K > x_C - bx_{NC} \geq 0$.

These conditions are necessary (but not sufficient) that collusion is sustainable at least under some circumstances in a two-period setting.[11] A final condition we need is that choosing to collude is not optimal for a firm if the other firm does not collude.

**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.

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

[11] In the infinite horizon extension of this model, $K$ can be set to zero and the second inequality is not necessary.

of the first period ($t = 0$). 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 never fully informative about the firm's action. We denote the firm's inference error with $\varepsilon$.

The critical difference between private and public ownership that we assume is that a public firm is obliged to report its cash flows (as well as other information informative about past and future actions).[12] This has two implications. First, the other firm's inference error $\varepsilon$ 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.

# 3 The Choice Between Public and Private Ownership

There are four main choices in this model: (i) whether firms that use the same technology will collude; (ii) whether the firms start developing the new technology; (ii) whether the innovator abandons the new technology at $t = 0.5$; 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. 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. 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, $x_C - K$.

[12] As pointed out in the Introduction, apart from their 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 $\varepsilon$ from primitives using Bayes rule. However, the reduced-form notation is sufficient for our purposes.

The key insight in what follows is that collusion can be sustained if both firms use the same technology for two periods, but this crucially depends on whether the firms choose public or private ownership. The key advantage of public ownership is that, by forcing firms to make their cash flows public, it helps them coordinate on future actions. We now clarify these points by focusing, first, on the equilibrium under private ownership.

**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, as otherwise the firms would have an incentive not to collude in period one.

Private ownership hampers collusion for two reasons. First, the inference error $\varepsilon$ is higher than with public ownership, which makes it less likely that collusion in period two can be sustained. For collusion in period two following signal $c$ to be preferable to not colluding, it must hold

$$(1-\varepsilon)\,x_C + \varepsilon\,(x_C - m) > (1-\varepsilon)\,bx_{NC} + \varepsilon x_{NC}. \tag{1}$$

Both sides of the inequality take into account that even if a firm colludes in period one, the other firm infers signal $nc$ with probability $\varepsilon$, which prompts that firm not to collude in period two. Such wrong inferences, leading to a breakdown in collusion, reduce the expected payoff from colluding in both periods.[13]

Second, even ignoring the effect on the inference error, private ownership hampers collusion by making it hard for firms to commit to abandon collusion when their cash flows are low (i.e., when they observe signal $nc$). The reason is that in a conjectured collusive equilibrium, such a signal indicating a deviation can only be wrong, 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 prefers ex post to neglect this signal and stick to the collusive strategy. Indeed, if the other firm has colluded in the first period, it expects that the private firm's cash flows are most likely high in which case both firms should collude again. However, then the best course of action for the private firm is to neglect its signal and continue colluding. The problem with this ex post incentive to avoid abandoning collusion regardless of the observed signal is that it invites the other firm to deviate in period one.

To see formally that a private firm that has colluded in the first period might ignore

[13] To get the expected payoff from colluding in period two, add $x_C$ to the left-hand side of (1). To get the deviation payoff from not colluding twice, add $bx_{NC}$ to the right-hand side of (1).

its signal and collude also in period two, consider the case in which both firms' signals are independent. Since both firms are supposed to collude in period one, they attribute signal $nc$ to the inference error $\varepsilon$, as non-collusion is an out-of-equilibrium (i.e., zero probability) event. In particular, 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 payoffs from colluding are equal to the left-hand side of expression (1) and the the expected payoffs from not colluding are equal to the right-hand side of expression (1). Hence, if the firm colludes after inferring $c$, it has the same incentive to collude after inferring $nc$. This makes it ex post suboptimal to go through with the threat of not colluding in the second period for any inference error $\varepsilon > 0$.

This problem could be 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 $\varepsilon$ in (1) differs depending on whether the firm infers $c$ or $nc$). Then, if $\widetilde{\varepsilon}$ is sufficiently high, the expected payoff from not colluding in period two becomes higher than that from colluding (as $x_C - m < x_{NC}$). Thus, not colluding following signal $nc$ could become a credible threat.[14]

**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 fact that the low cash flows must be reported helps firms coordinate on abandoning future collusion. Specifically, when low cash flows are common knowledge, both firms expect that the other firm should abandon collusion, making it individually optimal to do so themselves.[15] 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

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

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

to not collude in that period. The opposite holds if both firms observe signal $c$.[16] What further simplifies collusion is that the inference errors decrease, making the expected payoff from colluding in both periods

$$x_C - K + (1-\varepsilon)^2 x_C + \left(2\varepsilon - \varepsilon^2\right) x_{NC},$$

more likely to be higher than that from deviating and not colluding in both periods

$$bx_{NC} + (1-\varepsilon)\,\varepsilon b x_{NC} + \left(1 - \varepsilon + \varepsilon^2\right) x_{NC}.$$

**Proposition 1** ***(Public ownership as a collusion mechanism):*** *(i) Public ownership facilitates collusion. (ii) Collusion can only be achieved under private ownership if the firms' signals are sufficiently dependent and the inference errors are sufficiently small.*

**Corollary 1** *When firms using the same technology seek to collude, they find it easier to do so as public firms.*

To avoid trivial cases, we assume in what follows that collusion is always achieved under public, but never under private ownership.

## 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 only the innovator can develop the new technology (i.e., the incumbent's success likelihood is $\theta_{Inc} = 0$).

The problem is that if the innovator receives signal $\theta_M$ about the new technology, it might be tempted to respond aggressively by dropping the innovative technology and adopting the incumbent firm's technology. This temptation is especially strong with public ownership, as then both firms can collude and obtain high profits from the existing technology.

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

[16] 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.

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 $w_0 = 0$. In case the contract is renegotiated at $t = 0.5$, we denote with $\gamma$ the fraction of the additionally generated surplus that the R&D team can negotiate for itself (formalized in Appendix A).

The R&D team's incentive constraint is

$$U(\mathbf{w},1) - c \geq U(\mathbf{w},0), \tag{2}$$

where $U(\mathbf{w},e)$ denotes the R&D team's expected payoff depending on its effort $e$. Since, by optimality for the innovator, (2) will be satisfied with equality and the R&D team's outside option is zero, $U(\mathbf{w},0)$ 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 $\theta$ 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 ($\tau_G$) on the likelihood of landing in state $\theta_G$. However, there is also a second effect, which is negative. Exerting effort increases also the likelihood of state $\theta_M$ by $\tau_M$. Since this effort is wasted in case the new technology is abandoned in state $\theta_M$, 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 $\theta_M$ is more acute under public ownership, as then the outside option of colluding on the existing technology is ex post more attractive. This 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):*** *The inability to commit not to abandon the new technology in case of signal $\theta_M$ gives rise to a time inconsistency problem. At $t = 0$, such commitment would decrease the cost of hiring the R&D team, but sticking to this commitment at $t = 0.5$ might be infeasible if the innovator observes $\theta_M$. (ii) 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.*

The second part of Proposition 2 states that, despite making it easier to overcome the time-inconsistency problem, 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. Clearly, if the innovator does not even initiate the new technology's development, public ownership is always preferable.

## 3.3 Competition for Innovation and the Public-Private Choice

Suppose now that the incumbent also considers developing the new technology. The incumbent firm would do that if its success likelihood $\theta_{Inc}$ is sufficiently high to compensate it for its investment costs $k$. Note that we have assumed that the incumbent can always use the existing (old) technology, and would not need to abandon the development of the new technology at $t = 0.5$, as it does not face the innovator's trade off between developing the new or adopting the old technology.

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 $\theta_{Inc}$).

Second, competition makes it less likely that the innovator abandons the new technology at $t = 0.5$, as it will make zero profit from the incumbent technology if the incumbent develops the new technology. If the incumbent's success likelihood $\theta_{Inc}$ is sufficiently high, this effect could make the innovator's continuation decision under both public and private ownership the same. Specifically, if $\theta_{Inc}$ is high, the collusion prospects on the incumbent technology are not sufficiently likely to warrant abandonment in states $\theta_M$ and $\theta_G$ under both ownership types. In such cases, when the continuation decision under both ownership types is the same, the cost of hiring and motivating an R&D team is the same, making the collusion benefits of public ownership more valuable.

Overall, if the incumbent has a high likelihood of developing the new technology, the option to collude with the incumbent on the *new* technology could make public ownership preferable.

**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 $\widehat{\theta}_{Inc}$, such that the innovator always prefers public ownership for $\theta_{Inc} \geq \widehat{\theta}_{Inc}$. For $\theta_{Inc} < \widehat{\theta}_{Inc}$, either public ownership is again optimal or there is a threshold $\widehat{p}'_G(\theta_{Inc})$, such that the firm prefers public ownership if $p_G < \widehat{p}'_G(\theta_{Inc})$ and private ownership otherwise.*

Since in practice, $\theta_{Inc}$ and $p_G$ are likely to be correlated, assume for simplicity that $\theta_{Inc} = p_M\theta_M + p_G\theta_G + \delta$ (where $\delta$ could be positive or negative). Summarizing the results from this section, we obtain a U-shaped relationship between the attractiveness of innovation (as captured by $p_G$) and that of public ownership:

**Corollary 2** *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.*

Clearly, the higher the incumbent's cost $k$ of starting to innovate, the less likely would it be that case (iii) arises. If innovating means cannibalizing the firm's existing business, $k$ would be very large, and innovation would be more likely to come from private firms.

**Discussion** Throughout the paper we refer to coordination between the innovator and the incumbent as collusion. In practice, collusion could refer to outright cartel agreements or tacit collusion, which may fall more in the gray area of illegal coordination. Our model does not differentiate between the two. However, we expect illegal activity to be more concentrated in case (i) of Corollary 2, in which case firms are more likely to collude on existing technologies. This is because for coordination among firms to be deemed illegal by regulators, there must be a perceived harm to consumers. Thus, given that case (iii) is more likely to feature a positive effect on innovation, regulators may be more likely to tolerate coordination among firms in such cases.

Our model applies best to concentrated industries, as collusion would be more difficult to sustain as the number of firms increases. Furthermore, there is a lot of transparency regarding the actions of some firms regardless of whether they are public or private. This would be the case for firms whose standardized products can easily be compared. Typical examples are firms offering transportation services or firms whose products are easily compared on price-comparison websites. Such firms could achieve collusion even if they are private.

# 4 Extensions: Equity Stakes, Size, and Voluntary Reporting

A common practice of incumbents is to buy equity stakes in innovative firms or acquire such firms. In what follows, we turn to the question whether such stakes can act as a substitute to public ownership for achieving collusion. We then extend our model to analyze the effect of firm size and voluntary reporting on collusion and innovation incentives.

## 4.1 Coordination Through Equity Stakes

Suppose that the incumbent buys a non-controlling stake $\beta$ 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 bigger the incumbent's stake.

If the incumbent buys a controlling stake, however, collusion issues are no longer relevant. A natural specialization emerges 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 $\theta_M$. The latter two effects increase the likelihood that the innovator develops the new technology.

**Proposition 4** *(i) Buying a non-controlling equity stake in the innovator can help achieve collusion on the existing technology, but it 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.*

Overall, the main insight from this section is that buying equity stakes can help achieve collusion, but has additional effects on innovation incentives. Thus, collusion via public ownership and equity stakes are not perfect substitutes. However, one would expect that imposing additional (e.g., regulatory) costs on public ownership would make collusion through equity stakes more likely.

**Corollary 3** *An exogenous increase in the cost of public ownership increases the likelihood that collusion is achieved through controlling or non-controlling equity stakes.*

## 4.2 Size, Innovation, and Coordination

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 at no additional cost. Let $\varphi > 1$ be the scaling parameter, which increases expected profits to $\varphi x_{NC}$, $\varphi x_C$, and $\varphi x_{FM}$. Thus, scaling up does not affect the relative attractiveness of colluding versus not colluding for the innovator. However, the incumbent is hurt more if the innovator is larger and does not collude, as the incumbent's profits fall by $\varphi m$. Specifically, for the incumbent's cash flows, 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.

If Assumption 2 does not hold and the innovator adopts the incumbent's technology, the incumbent chooses the colluding action regardless of the action taken by the innovator. Intuitively, the incumbent would not bother to respond to a player who can steal only a small market share. Thus, the innovator can free ride and choose non-collusion while expecting that the collusion action will be the dominant strategy for the incumbent. This makes abandoning the new technology and adopting that of the incumbent more attractive at $t = 0.5$ compared to when the innovator is large. This has several implications.

First, if the innovator does not scale up, the choice between action $C$ and $N$ is the same under public and private ownership. Second, because the incumbent does not engage in "price wars" with the innovator, the innovator's incentives to abandon the new technology and adopt that of the incumbent are at least as high as those under public ownership in Proposition 1. Hence, its incentives to innovate are lower than those of the innovator, described in Section 3.2.

**Proposition 5** *If the innovator remains small, the incumbent plays the collusive action $C$ regardless of the innovator's action. In this case, the innovator is more likely to abandon the new technology and is indifferent between public or private ownership. Furthermore, its equilibrium payoff can be higher compared to when choosing to become large.*

An important consequence of Proposition 5 is that without the option to collude, the innovator may strategically decide to remain small to stay "under the radar screen" and in doing so avoid responses by the incumbent. To illustrate this, note that if the new technology's attractiveness is low (i.e., $p_G$ is low), the innovator abandons it when observing $\theta_M$ regardless of its size. This is because the cost of motivating the R&D team is the same regardless of the innovator's size. However, being small allows the innovator to steal market share from the incumbent technology, which could be more profitable than collusion. What is important, is that this might be preferable also for the incumbent. The latter can influence the innovator's size decision by not offering collusion opportunities to the innovator.

**Corollary 4** *The incumbent can affect the innovator's decision to remain small by not offering collusion opportunities to the innovator, i.e., by being private and not buying equity stakes in the innovator.*

## 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, contrary to private ownership. 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.

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 show that the private firm now would choose to communicate its report with noise. Let the true signal $s$ be observed correctly with probability $\eta \in (\underline{\eta}, 1]$. The lower bound $\underline{\eta} \geq \frac{1}{2}$ captures the private firm's discretion to communicate less precise information (i.e. adding noise), when choosing $\eta$. In what follows, 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 $c$ (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 $\eta$, 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. Intuitively, if the firm has colluded, it would like the other firm to continue colluding. If it has not colluded, it would prefer the other firm not to learn about it. Thus, when its cash flows in a conjectured collusive equilibrium are low, the private firm will choose to have $\eta = \underline{\eta}$. Second, comparing the payoffs of colluding and not colluding again in period two, colluding is ex post beneficial if

$$\eta \leq \eta^* \equiv \frac{x_C - bx_{NC}}{x_{NC} - bx_{NC} + m} \tag{3}$$

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 (3) 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, overall, we continue to obtain that private ownership reduces the likelihood of collusion even when voluntary reporting is possible. This reinforces our result that, by committing the firm to an ex post high reporting quality, public ownership helps sustain collusion and prevent a break down in collusive equilibria.

**Proposition 6** *With voluntary disclosure in the case of private ownership, a private firm has an incentive to add noise to its reporting when its first-period cash flows are low. This reduces the opportunities for collusion.*

# 5 Empirical Implications and Evidence

First, we discuss the implications of our model that are related to collusion on existing technologies (Implications 1–3). Subsequently, we discuss the model's predictions concerning the optimality of public or private ownership and buying equity stakes (Implications 4–7). Since our model is built around the notion that public firms are more likely to collude, we provide tentative empirical evidence for this result as well as for the predicted U-shaped relationship between the attractiveness of innovation and that of public ownership (see Section 5.2).

## 5.1 Empirical Implications

**Public ownership and collusion.** 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 that a larger firm at a turning point in its life-cycle may seek public ownership, which is surprisingly neglected in prior work: facilitating collusion in concentrated industries.

**Implication 1** *By committing firms to strict disclosure requirements, public ownership helps firms to avoid competition and facilitates collusion.*

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, with collusion we also refer more broadly to coordinating strategies that firms do not each into each other's business. This idea could help shed light on puzzling evidence, such as why profit margins in the tech, biotech and pharma industries are hard to square with competitive product markets.[17]

Recent advances in information technology have made it easier for private firms to disseminate valuable information about themselves to outsiders. If, as highlighted by Proposition 6, an exogenous decrease in the noise firms can add to their reports could allow also private firms to collude. With advances in new technologies, such as the blockchain, that further improve the verifiability of information, we expect such development to become even stronger—a possibility discussed recently also in Cong and He (2018).[18] This would negatively affect competition.

**Implication 2** *Advances in information technology that ease the credible dissemination of information would improve collusion prospects under private ownership, which would allow also private firms to retain high margins without going public.*

Similarly, the advantage of public relative to private ownership in terms of facilitating collusion will be less pronounced if it is easy for firms to observe the pricing decisions of competitors offering substitutes to their products or services (e.g., through price comparison websites). This may apply, for example, to firms offering transportation services, such as rail and air travel, which have been also historically prone to collusion.

An open question in recent empirical work is what could explain the declining popularity of public ownership in the U.S. (Gao et al., 2013). It seems that information disclosure requirements and compliance costs have increased the costs of going public. However, it has been argued that these costs alone cannot explain the decline of public ownership, and that this decline has been compounded by an increase in merger and acquisition activity (Doidge et al., 2016). Our paper suggests that these phenomena could be related, as acquiring equity stakes could substitute for public ownership in achieving collusion. Thus, when the cost of public ownership increases, firms are more likely to seek collusion via such equity stakes (Corollary 3).

**Implication 3** *An increase in the cost of public ownership will lead incumbent public firms to acquire private innovators (or public firms considering going private) or take equity stakes in such firms.*

[17] See Larry Summer's article cited in footnote 1. In Section 5.2, we offer empirical evidence consistent with Implication 1.

[18] 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.

Collusion can be achieved also through non-controlling equity stakes (Proposition 3). However, such collusion is not a perfect substitute for collusion via public ownership, as it reduces the innovation incentives of the firm that buys a stake by letting it free ride on the other firm's innovation. Another issue is that it is typically infeasible for small firms to buy stakes in much larger firms (Allen and Phillips, 2000). In such cases, collusion will only be achieved if the large firm is public, which in turn is more likely to be the case in countries in which the public equity markets are more developed. The latter is consistent with the evidence that corporate venture capital, which specializes in taking strategic minority stakes in innovators, is more prevalent in developed markets, but not associated with stronger competition in product markets (Dushnitsky, 2006).

In a recent paper Azar et al. (2016) find that financial investors, such as BlackRock, that own stakes in competing firms could contribute to softer competition among these firms. The paper's motivation is based on the argument that if the same investor owns, e.g., 50% of two firms, the management of either firm will take both firms' profits equally into account in their optimization decisions. Implication 1 cautions against drawing stark regulatory implications based on such findings, as public ownership alone could also act as a collusion mechanism.

**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 pursuing the development of a new technology. Specifically, it avoids the temptation of abandoning development in case of early difficulties created by the option to collude on the existing technology (Proposition 1).

**Implication 4** *If an innovator seeks to develop a new technology (and faces no competition on this from the incumbent), private ownership makes it more tolerant for failure, in the sense that it is less likely to abandon the new technology 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 2). 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. Collusion on the new technology could again literally mean not competing away the profits on the new product or service that is simultaneously developed. However, alternatively it could also mean coordinating strategies such that the firms focus on developing different aspects of a new technology— e.g., one firm developing the hardware, while another the software required to exploit a new technology. We predict that private ownership will be unambiguously better only when the innovation's expected profitability is intermediate.

**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 colluding with the incumbent on the new technology. For intermediate values, private ownership is more beneficial, as it helps to deal with the time inconsistency problem of not being able to commit not to prematurely abandon the new technology.*

Implication 5 could help understand why private firms are not always champions in innovation, despite the predictions of prior theory (Ferreira et al., 2012) and some empirical evidence (Bernstein, 2015). In case of a new technology that is expected to be highly profitable, firms might be pushed into the public market. Indeed, public firms, such as Apple, Google, Microsoft, and Tesla, are paramount examples of innovation.

In the spirit of the old idea that monopoly profits can help spur innovation, Proposition 4 predicts that public ownership that helps innovating firms avoid competition could improve innovation incentives:

**Implication 6** *If both the innovator and the incumbent seek to develop new technologies, public ownership could sharpen the incentives to innovate.*

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 5, we have the following prediction about how the firm's size interacts with collusion and its innovation incentives:

**Implication 7** *(i) Smaller private firms are more likely to switch to the incumbent technology compared to larger innovators, as they can undercut the incumbent without triggering a price war. (ii) Innovators might have incentives to remain small, but this is bad for their innovation incentives.*

What Implication 7 alludes to is that being small may offer distinct benefits. Small firms might be able to slightly undercut collusive pricing without triggering a competitive response.

## 5.2 Evidence

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.[19]

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.[20] We then manually match the defendants in these lawsuits to our IPO filings sample. 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.

### 5.2.1 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

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

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

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.[21]

The second challenge is finding evidence for collusive behavior. Antitrust lawsuits are an imperfect proxy that restricts attention to outright illegal avoidance of competition. One concern might be that the higher transparency of public ownership may also allow for better detection of 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 linking IPOs to antitrust lawsuits can only offer suggestive, but not conclusive, evidence. Still, there are factors that mitigate these concerns.

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).[22] 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, this should be true for all firms in our sample in the year following the filing (which we show below 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, DOJ or state attorney generals) that must further 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

[21] 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.

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

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.

#### 5.2.2 Results

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

$$\begin{aligned} IPO_i &= \alpha + \beta_1 \Delta Industry\ R\&D + \beta_2 \Delta Industry\ R\&D^2 + \beta_3 Industry\ R\&D + \beta_4 Industry\ R\&D^2 \\ &\quad + \gamma NASDAQ_i + \delta X_i + \nu_k + \mu_t + \varepsilon_i, \end{aligned} \tag{4}$$

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

$$\begin{aligned} AT_i^{post} &= \alpha + \beta_1 \Delta Industry\ R\&D + \beta_2 \Delta Industry\ R\&D^2 + \beta_3 Industry\ R\&D + \beta_4 Industry\ R\&D^2 \\ &\quad + \gamma IPO_i + \delta X_i + \nu_k + \mu_t + \varepsilon_i, \end{aligned} \tag{5}$$

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 $\beta_1$ and $\beta_3$ in equation (4) should be negative, while $\beta_2$ and $\beta_4$ 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.[23]

INSERT TABLE 2

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. We find only very weak evidence for a U-shaped relation between $Industry\ R\&D$ spending and antitrust lawsuits. However, this may also be consistent with our discussion following Corollary 2 that collusion is less likely to be prosecuted when firms' coordination spurs innovation,

In Appendix B, we describe further statistical tests that take into account the endogeneity of the IPO completion by instrumenting it with the two-month NASDAQ return following the IPO filing as in Bernstein (2015). These tests offer further support for Implication 1 (columns (4) and (5) in Table 2). In unreported regressions, we further find that all these results are robust to considering antitrust lawsuits in the three and five year windows around the IPO filing, but there is no effect in the first two years after the filing. As noted above, this finding is consistent with collusion taking time to take place and be detected, and inconsistent with frivolous lawsuits.

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

# 6 Conclusion

We develop a model that shows that the transparency that comes with public ownership helps facilitate collusion. For firms this can be particularly valuable if it preserves high margins on existing (commoditized) technologies. Not all firms benefit from public ownership, however. Being able to collude on an existing technology is a double-edge sword if an innovator seeks to develop a new technology, as then the temptation to abandon its development in case of early difficulties is high. This temptation to abandon the new technology is more acute under public ownership. Hence, private ownership helps to commit to the long-term pursuit of innovation and improves incentives.

[23] 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.

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, 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. Second, size matters too. 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 to avoid the need to collude. 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 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 $\theta_G x_{FM} > y_C > \theta_M x_{FM} > y_{NC}$ (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 $\theta$, as $\theta$ is non-contractible.

**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 $\theta_M$ if $y_C - w_A > \theta_M (x_{FM} - w)$. Since $\theta_M x_{FM} < y_C$, 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[24]

$$
\begin{aligned}
&(1 - p_M - \tau_M - p_G - \tau_G)(y_C - w_A) + (p_M + \tau_M)(y_C - w_A) \\
&+ (p_G + \tau_G)\,\theta_G (x_{FM} - w)
\end{aligned}
$$

subject to the R&D team's incentive constraint

$$
-(\tau_G + \tau_M) w_A + \tau_M w_A + \tau_G \theta_G w \geq c. \tag{6}
$$

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

$$
(1 - p_M - \tau_M - p_G - \tau_G) y_C + (p_M + \tau_M) y_C + (p_G + \tau_G)\,\theta_G x_{FM} - \frac{(p_G + \tau_G)}{\tau_G} c. \tag{7}
$$

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

$$
-(\tau_G + \tau_M) w_A + (\tau_M \theta_M + \tau_G \theta_G) w \geq c. \tag{8}
$$

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

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

$$\begin{aligned} &(1 - p_M - \tau_M - p_G - \tau_G)\, y_{NC} + (p_M + \tau_M)\, \theta_M x_{FM} \\ &+ (p_G + \tau_G)\, \theta_G x_{FM} - \frac{(p_G + \tau_G)\, \theta_G + (p_M + \tau_M)\, \theta_M}{\tau_G\theta_G + \tau_M\theta_M} c. \end{aligned} \tag{9}$$

Continuation after observing $\theta_M$ requires

$$\theta_M x_{FM} - y_{NC} > \theta_M w = \frac{\theta_M c}{\tau_G\theta_G + \tau_M\theta_M} \tag{10}$$

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

Suppose, next, that the inequality in (10) 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 $\gamma$ of the additionally generated surplus. Denoting the R&D team's payoff in that case with $w_R$, we have

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

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

$$-(\tau_G + \tau_M)\, w_A + \tau_M\, (w_A + \gamma\, (\theta_M x_{FM} - y_{NC})) + \tau_G\theta_G w \geq c. \tag{11}$$

It is optimal to set $w_A = 0$ and $w = \frac{c - \tau_M\gamma(\theta_M x_{FM} - y_{NC})}{\tau_G\theta_G}$.[25] The innovator's expected payoff is

$$\begin{aligned} &(1 - p_M - \tau_M - p_G - \tau_G)\, y_{NC} + (p_M + \tau_M)\, (\theta_M x_{FM} - \gamma\, (\theta_M x_{FM} - y_{NC})) \\ &+ (p_G + \tau_G) \left( \theta_G x_{FM} - \theta_G \frac{c - \tau_M\gamma\, (\theta_M x_{FM} - y_{NC})}{\tau_G\theta_G} \right) \\ = \;&(1 - p_M - \tau_M - p_G - \tau_G)\, y_{NC} + (p_M + \tau_M)\, \theta_M x_{FM} \\ &+ (p_G + \tau_G)\, \theta_G x_{FM} + \gamma\, (\theta_M x_{FM} - y_{NC}) \left( \frac{\tau_M}{\tau_G} p_G - p_M \right) - \frac{(p_G + \tau_G)}{\tau_G} c. \end{aligned} \tag{12}$$

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

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

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

we obtain

$$(1-p_M-\tau_M-p_G-\tau_G)(y_C-y_{NC})+(p_M+\tau_M)(y_C-\theta_M x_{FM})-c\theta_M\frac{\frac{\tau_M}{\tau_G}p_G-p_M}{\tau_G\theta_G+\tau_M\theta_M} \tag{13}$$

if there are no renegotiations under non-collusion, and

$$(1-p_M-\tau_M-p_G-\tau_G)(y_C-y_{NC})+(p_M+\tau_M)(y_C-\theta_M x_{FM})-\gamma(\theta_M x_{FM}-y_{NC})\left(\frac{\tau_M}{\tau_G}p_G-p_M\right) \tag{14}$$

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 (10) is satisfied. Furthermore, both (13) and (14) decrease in $p_M$, $p_G$, and $\tau_M$. Hence, there is 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 $\tau_M$, $p_M$, and $x_{FM}$.

Finally, note that if $\theta_M x_{FM} > y_C$, the continuation decision is the same under public and private ownership, and public ownership dominates. If $y_C > \theta_G x_{FM} > y_{NC}$, 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 $x_{FM}$ 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 $\theta_{Inc}$ 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

$$\theta x_{FM} + \frac{\theta_{Inc}}{1-\theta_{Inc}}\theta y_O < y_O. \tag{15}$$

Hence, the abandonment threshold is higher than without competition. In particular, since $\frac{\theta_{Inc}}{1-\theta_{Inc}}$ increases in $\theta_{Inc}$, 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 $\theta_M$, condition (15) holds for $y_C$, but not for $y_{NC}$, such that abandonment in state $\theta_M$ 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

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

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

$$\begin{aligned}&\left(1-p_M-\tau_M-p_G-\tau_G\right)\left(1-\theta_{Inc}\right)y_C+\left(p_M+\tau_M\right)\left(1-\theta_{Inc}\right)y_C\\&+\left(p_G+\tau_G\right)\left(\left(1-\theta_{Inc}\right)\theta_G x_{FM}+\theta_{Inc}\theta_G y_C\right)-\frac{\left(p_G+\tau_G\right)}{\tau_G}c.\end{aligned}$$

**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 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

$$\begin{aligned}&\left(1-p_M-\tau_M-p_G-\tau_G\right)\left(1-\theta_{Inc}\right)y_{NC}+\left(p_M+\tau_M\right)\left(\left(1-\theta_{Inc}\right)\theta_M x_{FM}+\theta_{Inc}\theta_M y_{NC}\right)\\&+\left(p_G+\tau_G\right)\left(\left(1-\theta_{Inc}\right)\theta_G x_{FM}+\theta_{Inc}\theta_G y_{NC}\right)-\frac{\left(\left(p_G+\tau_G\right)\theta_G+\left(p_M+\tau_M\right)\theta_M\right)}{\tau_G\theta_G+\tau_M\theta_M}c.\end{aligned}$$

Continuation after observing $\theta_M$ requires that

$$\left(1-\theta_{Inc}\right)\theta_M x_{FM}+\theta_{Inc}\theta_M y_{NC}-\left(1-\theta_{Inc}\right)y_{NC}>\frac{\theta_M c}{\tau_G\theta_G+\tau_M\theta_M}. \tag{16}$$

Suppose, next, that the inequality in (16) 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 $\gamma$ of the additionally generated surplus $w_R:=w_A+\gamma\left(\left(1-\theta_{Inc}\right)\theta_M x_{FM}+\theta_{Inc}\theta_M y_{NC}-\left(1-\theta_{Inc}\right)y_{NC}\right)$. 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 $\left(1-\theta_{Inc}\right)w+\theta_{Inc}w_{comp}=\frac{c-\tau_M w_R}{\tau_G\theta_G}$.[26] The innovator's

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

expected payoff is

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

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

$$\begin{aligned}&(1-p_M-\tau_M-p_G-\tau_G)(1-\theta_{Inc})(y_C-y_{NC})\\&+(p_M+\tau_M)((1-\theta_{Inc})\,y_C-(1-\theta_{Inc})\,\theta_B x_{FM}-\theta_{Inc}\theta_B y_{NC})\\&+(p_G+\tau_G)\,\theta_{Inc}\theta_G(y_C-y_{NC})-c\theta_B\frac{\frac{\tau_M}{\tau_G}p_G-p_M}{\tau_G\theta_G+\tau_M\theta_B}\end{aligned}\tag{17}$$

if there are no renegotiations under non-collusion, and

$$\begin{aligned}&(1-p_M-\tau_M-p_G-\tau_G)(1-\theta_{Inc})(y_C-y_{NC})\\&+(p_M+\tau_M)((1-\theta_{Inc})\,y_C-(1-\theta_{Inc})\,\theta_B x_{FM}-\theta_{Inc}\theta_B y_{NC})\\&+(p_G+\tau_G)\,\theta_{Inc}\theta_G(y_C-y_{NC})-\left(\frac{\tau_M}{\tau_G}p_G-p_M\right)w_R\end{aligned}\tag{18}$$

if there are renegotiations.

Let $\widehat{p}'_G(\theta_{Inc})$ define the value for $p_G$ at which (17) and, respectively, (18) is zero. To see when such a point exists, note that both (17) and (18) are positive for $p_G=\theta_{Inc}=0$, implying that public ownership dominates for these parameter values. Furthermore, taking the partial of (17) with respect to $p_G$ we have

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

and, respectively, of and (18) with respect to $p_G$

$$-(1-\theta_{Inc})(y_C-y_{NC})+\theta_{Inc}\theta_G(y_C-y_{NC})-\frac{\tau_M}{\tau_G}\gamma((1-\theta_{Inc})\,\theta_B x_{FM}+\theta_{Inc}\theta_B y_{NC}-(1-\theta_{Inc})\,y_{NC}).$$

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, (17) and (18) 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 $\widehat{p}'_G(\theta_{Inc})$, such that the innovator prefers public private ownership if an only if $p_G>\widehat{p}'_G(\theta_{Inc})$. Clearly, this point corresponds to $\widehat{p}_G$ Proposition 2.

To analyze the effects as $\theta_{Inc}$ 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 (17) with respect to $p_G$ and $\theta_{Inc}$, we obtain

$$(y_C - y_{NC}) + \theta_G (y_C - y_{NC}) > 0. \tag{19}$$

The positive sign of (19) implies that the increase in attractiveness of private ownership for higher values of $p_G$ is weaker for higher values of $\theta_{Inc}$, implying that a value $\widehat{p}'_G(\theta_{Inc})$ for which (17) is zero is less likely to exist for higher $\theta_{Inc}$.

The same insight obtains if the cross partial of (18) with respect to $p_G$ and $\theta_{Inc}$

$$(y_C - y_{NC}) + \theta_G (y_C - y_{NC}) + \frac{\tau_M}{\tau_G}\gamma (\theta_B x_{FM} - (1 + \theta_B) y_{NC}), \tag{20}$$

is positive. However, if (20) is negative, $\widehat{p}'_G(\theta_{Inc})$ is guaranteed to exist even for higher values of $\theta_{Inc}$ as long as $\theta_{Inc} < \widehat{\theta}_{Inc}$. **Q.E.D.**

**Proof of Corollary 2.** 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 (15)). 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 $\theta_B$ 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 (17) with respect to $p_G$ to obtain

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

The second derivative of (18) with respect to $p_G$ is

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

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.** (i) Let $\theta_{Inc}^{Innov}$ 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

$$V^{Inc} + \beta V^{Inov,comp} - k \geq \left(1 - \theta_{Inc}^{Innov}\right) y_C + \beta V^{Innov,no\ comp} \tag{21}$$

Differentiating both sides of (21) with respect to $\beta$, $V^{Innov,no\ comp} > V^{Inov,comp}$ implies that increasing $\beta$, makes condition (21) 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 $\theta_B$ . 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

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

As shown in Proposition 2, this leads to a lower compensation cost than if the new technology is abandoned in case of $\theta_B$ 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.**

**Proof of Proposition 5.** (i) 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.

(ii) One of four cases applies: 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.

In the first case, the innovator abandons the new technology following signal $\theta_B$ 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. 7) if

$$\begin{aligned} & \left(1 - p_M - \tau_M - p_G - \tau_G\right) 2bx_{NC} + \left(p_M + \tau_M\right) 2bx_{NC} + \left(p_G + \tau_G\right) \theta_G x_{FM} - \frac{\left(p_G + \tau_G\right)}{\tau_G} c \\ > \ & \left(1 - p_M - \tau_M - p_G - \tau_G\right) 2\varphi x_C + \left(p_M + \tau_M\right) 2\varphi x_C + \left(p_G + \tau_G\right) \theta_G \varphi x_{FM} - \frac{\left(p_G + \tau_G\right)}{\tau_G} c \end{aligned} \tag{22}$$

that is if $\varphi$ is sufficiently small relative to $b$. We omit the argument for the remaining regions, as it is analogous.[27]

Finally, note that if $m$ is sufficiently small, the incumbent might prefer that the innovator remains small despite stealing market share. The incumbent can influence this decision by choosing private ownership or not buying an equity stake in the innovator. To see this, observe that in these cases, we have to replace $x_C$ with $x_{NC}$ in the right-hand-side of inequality (22), which makes remaining small more attractive for the innovator. **Q.E.D.**

# Appendix B: Further Evidence

As noted in Section 5.2.1, 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 (4). 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 $X$.[28] 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).

[27] For example, in the second case the innovator's compensation cost is higher when it is small, as it continues developing the new technology if large (and private), but not if it is small. Remaining small is, thus, profitable if (see (13)):

$$(1 - p_B - \tau_B - p_G - \tau_G)(2bx_{NC} - 2\varphi x_{NC}) + (p_B + \tau_B)(2bx_{NC} - \theta_B \varphi x_{FM}) \geq c\theta_B \frac{\frac{\tau_B}{\tau_G} p_G - p_B}{\tau_G \theta_G + \tau_B \theta_B},$$

or respecitvely

$$\begin{aligned} & (1 - p_B - \tau_B - p_G - \tau_G)(2bx_{NC} - 2\varphi x_{NC}) + (p_B + \tau_B)(2bx_{NC} - \theta_B \varphi x_{FM}) \\ \geq\ & \gamma(\theta_B x_{FM} - y_{NC}) \left( \frac{\tau_B}{\tau_G} p_G - p_B \right) \end{aligned}$$

giving again a critical value for $\varphi$.

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

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 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%.

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) |
|---|---|---|---|---|---|
| Dependent variable | IPO | IPO | AT case after filing | AT case after filing | AT case 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. *, **, and *** indicate that the differences in means are statistically significant at the 10%, 5%, and 1% level, respectively. 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 |

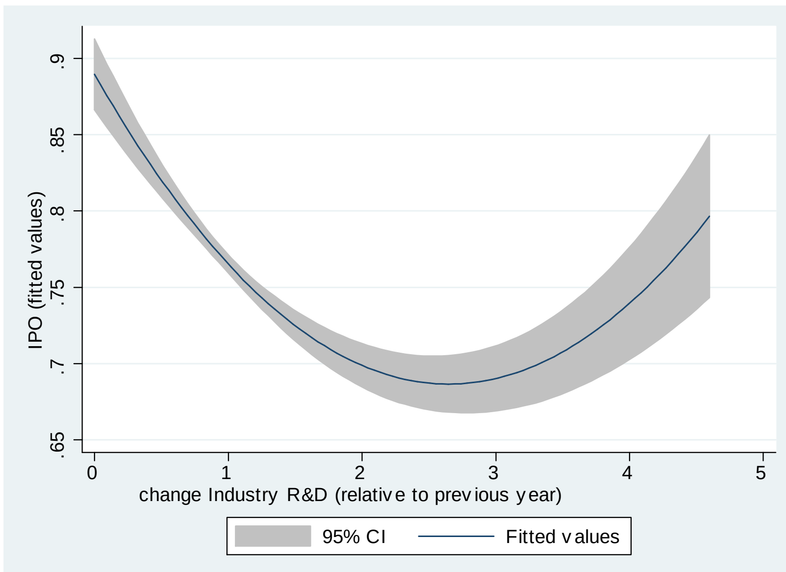


Figure 2: **Quadraticly fitted relation between IPO and ΔIndustry R&D.** The figure plots the fitted values of IPO from model (1) in Table 2 against $\Delta Industry\ R\&D$, which is the change in average R&D spending to total assets in the same two-digit SIC industry in the IPO filing year relative to the previous year. The gray area presents the 95% confidence interval.