Collusion with Public and Private Ownership and Innovation

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January 21, 2019

Abstract

We argue that, by enforcing the regular provision of vetted information, public ownership can help firms coordinate to avoid head-to-head competition. Such "collusion" opportunities increase profitability ex post, but could lead to time-inconsistency problems undermining innovation ex ante. We show that public ownership benefits firms for which innovation is either of limited importance — so coordination on existing technologies is key — or of first-order importance — so coordination with rivals developing the same technology is key. Private ownership dominates for intermediately attractive innovation opportunities, where time inconsistency problems are prevalent. The predictions of our model 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

Stringent disclosure requirements are said to hurt public firms by forcing them to reveal information to competitors (Bhattacharya and Ritter, 1983) and by inducing them to neglect long-term strategies (Stein, 1989), such as investing in innovation. However, there is little evidence that the decade-long increase in disclosure requirements explains the recent decline in public ownership (Gao et al., 2013; Doidge et al., 2017). What is more, public ownership has gone hand in hand with record profits over this period. Particularly remarkable is that the ten-year annualized returns of the S&P 500 Biotechnology (17%), Information Technology (17%), and Technology (15%) Select Industry Indices — containing firms arguably sensitive to disclosing information — easily outperform the market at large. Furthermore, though going public might have ambiguous effects on how firms innovate (Bernstein, 2015; Acharya and Xu, 2017, Gao et al., 2018), one thing seems clear: With the share of patents produced by public firms at 40% (and rising) and with these patents being more cited, public firms are major drivers of innovation.[1] Thus, it is an open question whether stricter disclosure requirements might have *helped* some public firms support both innovation and high profits. What is interesting, is that these developments have coincided with a secular decline in competition among public firms (De Loecker and Eeckhout, 2017).[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. These opportunities are not restricted to legally questionable strategies like coordinating on prices or quantities, but could involve entirely legitimate differentiation strategies in line with the prescriptions of the strategy literature. A typical example would be when firms face no barriers to compete head-on, yet tacitly coordinate on focusing on different market segments.[3] A key factor helping firms coordinate is mandatory

[1] The index returns are as of January 2019; the patent statistics are based on Kogan et al.'s (2017) dataset.

[2] See "Special report: Competition" (The Economist, 17 November, 2018) and "Economists warn on dominance of US corporate giants" (FT, 14 August, 2018), which are also based on data from public firms.

[3] Both tacit and illegal collusion are pervasive. Recent cartel cases include Procter and Gamble, Unilever, Bausch & Lomb, Sony, Toshiba, LG, Nvidia, BMW, Daimler, VW, GM, Ford, ExxonMobil, Verizon, AT&T, Visa, Master Card, Metro Goldwyn Mayer, News Corp, UPS, Northwest Airlines. Appendix B shows that public firms are several times more likely to face antitrust lawsuits than comparable private firms.

reporting on things such as investments, new products and services, large customers, R&D, and even basic information, such as sales figures. Naturally, these coordination opportunities are easier in more concentrated markets. We show that voluntary reporting by private firms cannot play the same role for coordination.

Linking coordination opportunities to being public explains now why the stricter disclosure requirements of public ownership can either hurt or spur innovation. The negative effect of coordination is that, by increasing the margins on existing services and products, it makes abandoning the development of new technologies in the face of early difficulties more likely. If such abandonment occurs, it creates time-inconsistency problems related to committing to innovation. We show that the resulting cost leads to a U-shaped relationship between the preference for being public and the attractiveness of innovation. Being public is beneficial if the value of innovation is low relative to the margins that can be earned on already existing technologies. Commitment to innovation is then a secondary concern. This case would be typical for firms in industries with relatively stable technologies and business models or in declining industries that may benefit from consolidation, but face antitrust hurdles. However, being public can also be beneficial at the other extreme, where firms face highly attractive innovation opportunities that are being explored also by their rivals. Premature abandonment of innovation is then not a concern, and there is a benefit from coordinating on simultaneously developed new technologies. Examples include highly technological and R&D-driven firms that compete with their rivals to introduce the "next big thing." For innovations in the middle spectrum, private ownership dominates. The ability to commit to a long-term innovation strategy is then important for stimulating effort towards the new technology's development. This case may be particularly relevant for industries in which rivals are less attracted to innovation, as it is not likely to be disruptive. The lesser transparency of private ownership could also help in safeguarding the firm's technological lead by not making rivals aware of the new technology's development and delaying their entry.

To formalize these insights, we develop a model featuring two firms — an innovative player ('the innovator') and an incumbent — that operate in the same market over two periods and can choose to be public or private. This setting has two main elements. First, in the initial period, the innovator can start developing a new technology, which requires hiring an R&D team that needs to be motivated to exert unobservable effort. At a cost, the incumbent can also start developing the new technology next to operating the existing one. Subsequently, the innovator obtains a signal indicating the new technology's profitability. At that point, the innovator can abandon exploration and fall back on the existing technology. The second main element of our model is that, when both firms use the same technology, they might try to engage in tacit collusion. What stands in the way of colluding, however, is that each firm faces a type of a prisoner's dilemma: Coordination over two periods is beneficial, but firms might have incentives to deviate. Such deviations are difficult to detect, since firms can only make noisy inferences about the other firm's actions.

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

The reason a private firm cannot replicate the same collusion equilibrium is that its threat to abandon collusion would not be credible. The problem is that without observing the private firm's cash flows, its counterpart would not know when a trigger strategy of abandoning collusion is about to be played. Since in a collusive equilibrium such abandonment is not very likely, the private firm's counterpart would most likely continue to collude, making it optimal for the private firm to do the same even its cash flows turn out to be low. This ex post incentive not to act on signals pointing at a deviation from collusion invites such deviations and makes it impossible to support a collusive equilibrium.

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

The already described U-shaped relationship between the attractiveness of innovation and that of public ownership reflects this trade-off. Specifically, the coordination opportunities facilitated by public ownership are beneficial either when innovation is not very attractive (coordinating on the existing technology is then key) or so attractive that also the incumbent pursues it (coordination on the new technology is then key).

Our predictions would be reinforced if we would take into account that private ownership could help the innovative firm hide its effort to develop the new technology. Such considerations would be particularly relevant for intermediately attractive technologies not (yet) being explored by the incumbent. The innovative firm would then seek to develop such technologies without alerting its rival. This could also help delay entry of new players.

We extend the model along several dimensions. First, we analyze the innovator's decision to scale up and grow. By remaining relatively small, an innovator may be able to chip away market share from incumbents without triggering a competitive response. This could create incentives to stay 'below the radar screen' by remaining small and private. Crucially, it also encourages the innovator to use the incumbent technology and, hence, reduces its innovation incentives. Second, we analyze investing in the competitor's equity as an alternative way to achieve collusion. When buying an equity stake in the innovator, the incumbent's own innovation incentives are reduced as it benefits from the innovator's payoffs. Yet the overall effect on innovation is ambiguous, as the innovator's innovation incentives are stronger given that less competition on the new technology would lead to higher expected profits from innovating. Third, we show that achieving collusion through voluntary reporting is hard, as absent exogenous strict reporting requirements, private firms would have ex post incentives to add noise to their reports. We conclude with an extensive discussion of the empirical predictions of our model.

Related Literature. 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 one of the text-book difference between public and private ownership that public firms face stricter disclosure requirements than private firms. In particular, while the prior literature has highlighted that such disclosure could leak sensitive information and make firms reluctant to go public (Bhattacharya and Ritter, 1983;

Maksimovic and Pichler, 2001), we point out that the commitment to sharing information could make being public attractive for firms, as it could help them avoid competing with each other. This is particularly relevant in concentrated markets. Thus, our paper links the corporate finance to the industrial organization literature on collusion and competition (Green and Porter, 1984). Related papers include Matthews (2006), who analyzes the effect of interfirm equity stakes on competition and innovation; Fulghieri and Sevilir (2011) and Phillips and Zhdanov (2013) who analyze the effect of takeovers on innovation; Chod and Lyandres (2010) who argue that the better diversification of investors in public firms gives these firms a strategic advantage in more competitive industries; and Kang and Lowery (2014) and Hatfield et al. (2017) who model collusion among IPO underwriters. Our contribution to this body of work is to analyze how the choice between being public or private interacts with firms' collusion and innovation incentives.

In line with our premise that public ownership may help facilitate collusion, the law literature has discussed the concern of regulators that conference calls with stock analysts could act as a means of disclosing unscripted sensitive information to rivals, inviting collusion (Steuer et al., 2011).[4] Related, Bourveau et al. (2017) document 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 analyzing the effects of collusion on innovation. Equally important, we show why private firms cannot replicate a collusive equilibrium by *voluntarily* disclosing information: 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 complement Ferreira et al. (2014) who analyze a setting in which private ownership facilitates exit of investors in the absence of time inconsistency problems. They argue that the lack of transparency associated with private financing makes it hard for outsiders to distinguish whether a private investor exits due to an illiquidity shock or because the firm's innovation has failed.

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

Somewhat reminiscent of Grossman and Stiglitz's (1980) information efficiency paradox, this makes it less costly for private investors to exit. The better exit option under private ownership is desirable in Ferreira et al. (2014), as it makes investors ex ante more willing to invest in innovation. In contrast, we emphasize the importance of endurance and commitment. Another difference is that private ownership in their paper always dominates when exploring new ideas. Instead, we predict a U-shaped relationship between the attractiveness of innovation and that of private ownership. These differences, as well as our model extensions, generate an interesting contrast in empirical predictions.[5]

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

Our analysis relates also to more than fifty years of industrial organization literature analyzing the effect of market concentration on innovation.[6] The novel aspect of our paper is that it studies how the choice between public and private ownership interacts with collusion opportunities and innovation. We show that such interactions could shed light on a number of stylized facts that are hard to reconcile with prior theory.

[5]Observe that financial constraints do not feature in our model. Such constraints could also affect the choice between public and private ownership. For example, public ownership could facilitate innovation by making it easier to access investors with more-aligned beliefs (Allen and Gale, 1999; Boot and Thakor, 2006). Empirically, Acharya and Xu (2017) find that public firms in external finance dependent industries spend more on innovation and have a better innovation profile than private firms.

[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.

2 Model

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

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

At the interim date $t = 0.5$ of the first period, the innovator observes a non-verifiable signal that shows the value of θ. At this point in time, if the innovator has started the new technology, it can still abandon it and compete in the first period with the incumbent technology. We assume that the decision whether to abandon the new technology lies with the innovator, and not the R&D team.[7]

Unlike the innovator, the incumbent firm operates the old technology from the beginning of the first period. It can try to develop in addition the new technology, but it would incur a deadweight cost k of diverting resources. This cost could also be interpreted as the cost of cannibalizing the firm's existing business or acquiring a firm that has the necessary know-how to help develop the new technology. We denote the expected probability that the incumbent

[7] Observe that renegotiations at $t = 0.5$ would lead to the same continuation decision regardless of who decides on continuation: 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 $t = 0.5$).

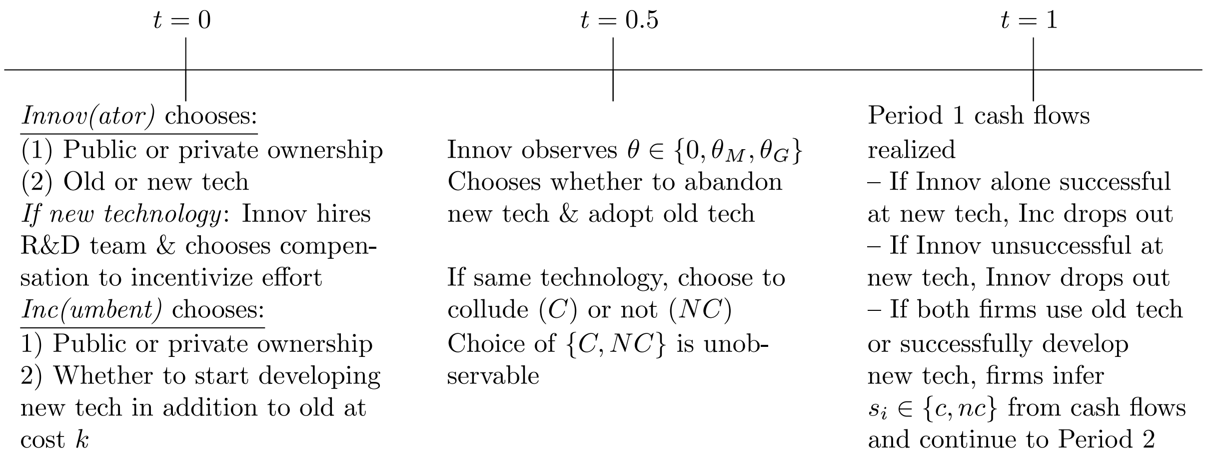

Figure 1: **Timeline of first period.** If both firms survive the first period, they operate the same technology in the second period and choose again whether to coordinate in the beginning of that period.

successfully develops the new technology with θ_{Inc}, and, for simplicity, we assume that no additional information about θ_{Inc} is revealed at $t = 0$.[8]

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

Coordination Problem if Both Firms Use the Same Technology What do we mean by collusion and how does it work? We stipulate that in each period when using the same technology, both firms decide whether to collude (action C) or not collude (action NC). As

[8] We want to capture the realistic situation in which the incumbent may not want to pursue all innovation opportunities that the innovator pursues. The deadweight cost k guarantees this.

emphasized in the introduction, we use the term "collusion" broadly to refer to any action or, respectively, lack of action that helps avoid head-to-head competition. For example, the firms may allow each other to pursue distinct strategies even if they face no technological hurdles that would stop them from competing.[9] The choice of action $\{C, NC\}$ affects the firms' cash flows, which are stochastic and realized at the end of the respective period. If both firms collude in a given period, their expected cash flows when utilizing the same technology in that period are x_C for each. If neither firm colludes, their expected cash flows are lower: $x_{NC} < x_C$. If one of the firms tries to collude, while the other does not, the former firm's expected cash flow is $x_C - m$, while the latter firm's expected cash flow is bx_{NC}, with $m > 0$ and $b > 1$.

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

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

The first inequality introduces a prisoner's dilemma in a one-shot game (single period), making collusion over just one period impossible. The second inequality makes collusion potentially possible in a two-period setting.[10]

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

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

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

Information Structure and Public vs. Private Ownership We assume that the decision whether the firm should be public or private is made at the beginning of the first period ($t = 0$) and cannot be revoked until the end of that period. Neither firm's action C or NC is observable, but at the end of every period, each firm i infers a signal $s_i = \{c, nc\}$

[9]This aspect relates our paper also to the literature analyzing collusion when firms' products are not perfect substitutes (e.g., Chang, 1991; Ross, 1992).

[10]In the infinite horizon extension of our model, the second inequality would not be necessary, and we could set $K = 0$.

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

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

about whether or not the other firm has colluded. The signal is based on each firm's own cash flows and the information reported by the other firm. Note that since cash flows are stochastic (x_C and x_{NC} are the expected values), they are not fully informative about the firm's action. We denote the likelihood of making the wrong inference with $\varepsilon \in \left[0, \frac{1}{2}\right]$.

The critical difference between private and public ownership that we assume is that a public firm is obliged to report its cash flows.[11] This has two implications. First, the other firm's inference error weakly decreases, since its signal is based on more information. Second, the other firm can infer the signal that the public firm infers from its cash flows. Initially, we assume that the decision to start developing the new technology is observable to all regardless of whether the firm is public or private.

3 The Choice Between Public and Private Ownership

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

In what follows, we show that public ownership facilitates collusion if both firms use the same technology, i.e., if both firms use the incumbent or if both successfully develop the new 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 in the sense of abandoning it too

[11] Though in what follows we speak of inferring signals from cash flows, public firms are obliged to report also other information indicative of past and future actions. At the expense of introducing additional notation, we could model these effects explicitly and derive ε from primitives using Bayes rule. However, the reduced-form notation is sufficient for our purposes. In Section 4.3, we extend the model to account for voluntary reporting by private firms.

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

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

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

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

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

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

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

$$(1-\varepsilon)\,x_C + \varepsilon\,(x_C - m) > (1-\varepsilon)\,bx_{NC} + \varepsilon x_{NC}. \tag{2}$$

These expected payoffs take into account that, even if a firm colludes in period one, the other firm infers signal nc with probability ε, which prompts that firm not to collude in period two. Such wrong inferences (high ε) about whether the private firm sticks to the collusion equilibrium make it more likely that it abandons collusion in period two, which, in turn, undermines the incentives to start colluding in period one.

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

The problem that a private firm that has colluded in the first period might ignore its signal and collude also in period two is most pronounced when both firms' signals are independent. Signal independence means that if both firms collude in period one, the private firm expects that, regardless of its own signal, the other firm receives signal c with probability $1 - \varepsilon$ and, thus, colludes also in period two with such probability. Hence, *regardless of its signal*, the private firm's expected payoff from colluding is equal to the left-hand side of expression (2), and the expected payoff from not colluding is equal to the right-hand side of expression (2). Thus, if it is optimal for the private firm to collude after inferring c, it is also optimal to collude after inferring nc. As a result, with independent signals, the threat of abandoning collusion in case of low cash flows is not credible for *any* inference error $\varepsilon > 0$.

This problem is ameliorated if both firms' signals are dependent and if that implies that, after observing nc, the conditional likelihood $\widetilde{\varepsilon}$ that also the other firm has inferred nc is higher compared to after observing signal c (in this case, the inference error ε in (2) differs depending on whether the private firm infers c or nc). Then, if $\widetilde{\varepsilon}$ is sufficiently high, the expected payoff from abandoning collusion in period two may become higher than that from colluding. That is, for the threat of abandoning collusion after privately observing signal nc to become credible, we need not only small inference errors, but also sufficiently strong signal dependence.[12]

Public ownership. By committing the firm to report its cash flows, public ownership circumvents the problem that a private firm has an ex post incentive to neglect signal nc. Though also under public ownership the firms know that in a conjectured collusive equilibrium, low cash flows must be due to bad luck rather than a deviation by the other firm, the key difference is that a public firm must report its low cash flows. This helps firms coordinate on abandoning future collusion. Specifically, when a public firm reports low cash flows, the other firm knows that the public firm is supposed to abandon collusion. Anticipating this, it is better off abandoning collusion also itself. Thus, it becomes mutually optimal for both firms to abandon collusion.[13] With credible punishments now in place, a collusive equilibrium can be sustained.

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

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

Specifically, the equilibrium candidate under public ownership can be amended as: collude in the first period, and collude in the second period if and only if *both* firms observe signal c. In this case, if a firm observes signal nc, this becomes common knowledge and the expectation that it will not collude in period two makes it, indeed, a mutual best response for both firms not to collude in that period. The opposite holds if both firms observe signal c.[14] Signal dependence is irrelevant for this argument, as the commonly observed signal becomes a coordination device on what action to take in period two.

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

$$\begin{aligned} 0 \;\leq\;& x_C - K + (1-\varepsilon)^2 x_C + \left(2\varepsilon - \varepsilon^2\right) x_{NC} \\ & - \left(b x_{NC} + (1-\varepsilon)\,\varepsilon b x_{NC} + \left(1 - \varepsilon + \varepsilon^2\right) x_{NC}\right). \end{aligned} \tag{3}$$

Expression (3) becomes easier to satisfy when the inference errors decrease, and, for $\varepsilon \to 0$, it reduces to the full information benchmark in (1).

Proposition 1 ***(Public ownership as a collusion mechanism):*** *A coordination/collusion equilibrium is easier to support with public than with private ownership.*

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

3.2 Abandoning the New Technology with Public and Private Ownership

Given the option to increase the firm's cash flows through collusion with public ownership, one might wonder why not all firms go public in our model. The answer is that collusion

[14]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.

might undermine innovation incentives. Instead, choosing private ownership can serve as a commitment mechanism. To make the point, suppose for now that the incumbent is public and that it is common knowledge that it does not engage in innovation.

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

Though the option of early termination might be valuable ex post, it could reduce the R&D team's incentives to exert effort ex ante. Let $\mathbf{w} = \{w_0, w_A, w\}$ be the contract the innovator offers the R&D team, which pays w_0 in case of zero cash flows, w_A in case the new technology is abandoned, and w in case the new technology is successful and yields positive cash flows. Note that the R&D team's wage can only be contingent on what is verifiable, i.e., the innovator's decision to continue or abandon the new technology and the subsequent cash flows. Since the innovator is protected by limited liability, we can set $w_0 = 0$. We allow that the contract is renegotiated at $t = 0.5$, in which case γ denotes the fraction of the additionally generated surplus that the R&D team can negotiate for itself.

The R&D team's incentive constraint is

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

where $U(\mathbf{w},e)$ denotes the R&D team's expected payoff depending on its effort e. Since, by optimality for the innovator, (4) will be satisfied with equality and the R&D team's outside option is zero, $U(\mathbf{w},0)$ 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 θ realization has two effects on effort. One is the standard positive disciplining effect of not getting paid ($w_A = 0$) if the new technology is abandoned. The strength of this effect increases in the impact of effort on the likelihood of landing in state θ_G (i.e., in τ_G). However, there is a second effect, which is negative. Exerting effort increases also the likelihood of state θ_M by τ_M. Since this effort is wasted in case the new technology is abandoned in state θ_M, such abandonment makes it more difficult to satisfy the R&D team's incentive constraint. We show in the Appendix that this negative effect dominates if $\tau_M > \tau_G \frac{p_M}{p_G}$ (or equivalently $p_G > \frac{\tau_G}{\tau_M} p_M$). 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 main insight is that the resulting time inconsistency problem of being unable to commit not to abandon the new technology in case of state θ_M is more acute under public ownership, as then the outside option of colluding on the existing technology is ex post more attractive. This tension between ex ante and ex post efficiency could make private ownership ex ante preferable. This occurs if the ex ante expected profitability of the new technology is sufficiently high (and it holds at least that $p_G > \frac{\tau_G}{\tau_M} p_M$). Then, the innovator needs to share more rent with the R&D team, while benefiting less from the better collusion possibilities of public ownership in states $\theta = \{0, \theta_M\}$, as these states are less likely to occur. Hence, the time inconsistency problem is particularly costly when the new technology is sufficiently attractive.

Proposition 2 ***(Time inconsistency with public and private ownership):*** *Suppose that innovation comes only from the innovator. The innovator's inability to commit not to abandon the new technology in case of signal θ_M gives rise to a time inconsistency problem. There is a threshold for $\widehat{p}_G$, such that the innovator prefers public ownership if $p_G < \widehat{p}_G$, and private ownership otherwise.*

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

3.3 Competition for Innovation and the Public-Private Choice

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

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

Second, when the incumbent also tries to develop the new technology, the option to abandon its development at $t = 0.5$ becomes less attractive for the innovator. In the extreme, in which the incumbent is always successful at innovation, the only way for the innovator to survive is to continue innovating regardless of its interim signal. In this case, private ownership has no commitment benefit. Thus, being public is preferable, as it would help coordinating to avoid competition if both firms successfully develop the new technology.

Proposition 3 ***(Competition for innovation)*** *Suppose that both firms compete to develop the new technology. An advantage of public over private ownership is that the firms can collude not only on the incumbent, but also on the new technology if the latter is successfully developed by both firms. There is a threshold $\widehat{\theta}_{inc}$ for the success probability of the incumbent such that the innovator prefers public ownership if $\theta_{inc} > \widehat{\theta}_{inc}$. For $\theta_{inc} < \widehat{\theta}_{inc}$, there is a threshold $\widehat{p}'_G(\theta_{Inc})$ such that the innovator prefers public ownership if $p_G < \widehat{p}'_G(\theta_{Inc})$ and private ownership otherwise.*[15]

The main addition relative to Proposition 2 is that public ownership dominates for the innovator if the incumbent's likelihood θ_{inc} of developing the new technology is sufficiently high. The implication would be that public ownership dominates for the innovator either if innovation is sufficiently unattractive or if it is very attractive for both firms. This leads to a roughly U-shaped relation between the attractiveness of innovation and that of public ownership. We have:

Corollary 1 *(i) Public ownership is optimal for the innovator if the attractiveness of innovation for both the incumbent and the innovator is either low or high. (ii) Private ownership is optimal for the innovator for innovation opportunities that are not sufficiently attractive*

[15]The threshold $\widehat{p}'_G(\theta_{Inc})$ may be so high that public ownership is always preferable for the innovator.

for the incumbent, but are sufficiently attractive for the innovator — i.e., typically intermediately attractive innovation opportunities.

The results of Corollary 1 can also be related to the incumbent's cost k of starting to innovate. For example, if for the incumbent the cost of cannibalizing the firm's existing business or externally acquiring the human capital or skills needed to develop the new technology are very large (k is high), the incumbent would not innovate. In this case, Proposition 2 would be a better description for the innovator's choice between public and private ownership.

3.4 Discussion: Information Leakage, Entry, and Other Interpretations

Reporting on the Development of the New Technology So far we have assumed that the difference between public and private ownership is that public ownership forces the firm to report its cash flows, and we have shown that this facilitates tacit-= collusion. However, another difference between public and private ownership is that significant new investments or changes in strategy must be reported by public, but not by private, firms.[16] Thus, in line with the literature emphasizing the revelation of valuable proprietary information upon going public (Bhattacharya and Ritter, 1983; Bhattacharya and Chiesa, 1995), a firm may prefer private ownership to avoid alerting its rival that it is developing a new technology. Leakage of such information could encourage the incumbent to start developing this technology as well. This insight reinforces our result that for intermediate expected profitability of innovation (i.e., values for which the incumbent would not initiate the development of the new technology if uncertain about its rival's intentions), the innovator will choose to stay private. Being private now helps not only because it commits the innovator to a long-term innovation strategy (no time-inconsistency problem), but also because it helps avoid competition on that strategy. However, if innovation is sufficiently attractive and the incumbent or new rivals engage in it anyhow, being able to coordinate with the incumbent on the development of the new technology becomes important. Being public would then again be beneficial. Thus, we see our theory of coordination as one complementing rather than contradicting prior work on the leakage of proprietary information.

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

A related aspect is that the incumbent with deeper pockets may try to preempt the innovator from developing a new technology if it becomes aware that the innovator has such intentions. In the case of positive investment costs (which we have not modelled), an early entry by the incumbent in the development of the new technology could accomplish this if the new technology is intermediately attractive. This would be another reason for the innovator to remain private not to alert the incumbent of its intentions.

New Entry and Life-Cycle Effects Our model could be extended to allow for entry of new competitors. Such entry would have the following effects. First, relating to the preceding discussion, it would add another reason why, for intermediately attractive innovation opportunities, the innovator may decide to stay private. Specifically, when potential new rivals are not (yet) aware that entering the innovator's turf could be profitable, staying private and avoiding the leakage of such information could delay their entry. Second, entry could further reduce the benefit of being public if the disclosure of high profits attracts new rivals. With a larger number of players, coordination would be also more difficult to achieve.

Overall, allowing for entry leaves the U-shaped prediction unchanged, but it would increase the intermediate region in which being private is preferable. The implication is that being private would be more preferable in industries with lower barriers to entry. We should note, however, that the barriers to entry can also be endogenous, as better coordination opportunities under public ownership could make it easier to prevent entry by rivals. For example, firms could temporarily accept a reduction in profits (by coordinating on lower prices, higher quantities, etc.) to stave off new entrants from stealing market share and subsequently revert to more profitable strategies.

Finally, it is worth noting that, even if a firm prefers to be private while still developing a technology, once it starts using it and the new technology becomes the new standard, the firm could benefit from going public and being able to coordinate with its rivals. This observation is in line with life-cycle theories of the firm in which a firm goes public once it reaches a sufficient state of development. Here this happens if the firm has already established itself, launched the innovation, and does not look for further disruptive changes, but rather to protect its margins. In such cases, further innovation might be pursued as a precaution or a diversification strategy and could force the firm to branch out outside its core industry.

Alternative Interpretations Our model highlights the importance of commitment to the regular and credible reporting of information. The model applies best to concentrated industries, as coordination is easier to achieve with fewer players. More broadly, we could rephrase Propositions 1-3 as a firm choosing whether to participate in a mechanism forcing it to report information about itself. Apart from public ownership, such a mechanism is offered also by industry associations collecting price and trade statistics, which are then made available to members.[17] When it comes to coordination, such information may substitute for information disclosed by public firms. Our predictions for how coordination opportunities interact with innovation incentives would apply also to such cases.

4 Extensions: Size, Equity Stakes, and Voluntary Reporting

Our baseline analysis made several simplifying assumptions that helped us distill the main novel economic forces. Some of these assumptions included that the innovator and the incumbent were of the same size and that going public entailed no costs for the innovator. In what follows, we relax these assumptions and derive several additional predictions. Additionally, we discuss buying equity stakes and voluntary reporting as alternative ways of achieving coordination and compare the implications for innovation.[18]

4.1 Size, Innovation, and Coordination

Consider, first, the effect of firm size. In this section, we extend our baseline model by introducing a date $t = -1$ at which the innovator can choose to operate at a larger scale (for simplicity, at no additional cost). Let $\varphi > 1$ be the scaling parameter, which increases expected profits to φx_{NC}, φx_C, and φx_M. Thus, scaling up does not affect the relative

[17] A good example is The Open Competition Plan. This plan involved a central clearing house for information on prices, trade statistics and practices, with the aim of keeping all members fully and quickly informed of what the others have done. Though this plan was struck down by antitrust authorities, there are still various industry associations offering similar services.

[18] In this paper, we have emphasized the link between collusion and innovation as it relates to being public. However, other effects might be present as well. For example, better coordination opportunities under public ownership could ease financing constraints and could change the type of innovation that the firm chooses to undertake.

attractiveness of colluding versus not colluding for the innovator. However, the innovator's size matters for the incumbent, as its losses from non-collusion are higher when the innovator chooses to be large. Specifically, the incumbent's profits fall by φm, and we assume that $x_C - \varphi m < x_{NC} < x_C - m$. That is, Assumption 2 is satisfied if the innovator is large, but not if it is small. Then, if both firms use the same technology and the innovator chooses to remain small, the incumbent chooses the colluding action regardless of the action taken by the innovator. Intuitively, it is not worth starting a price war with a small rival who chooses to be a marginal player.

A small innovator can then free ride and choose non-collusion while expecting that the collusive action will be the dominant strategy for the incumbent. Clearly, this could make remaining small and "staying under the radar screen" more profitable than growing large and having to coordinate with the incumbent. If the innovator chooses to remain small, the choice between public and private ownership no longer affects the action C or N. Furthermore, because the incumbent behaves cooperatively regardless of what the innovator is doing, the innovator's incentives to abandon the new technology and adopt the incumbent's technology are higher compared to when it would have chosen to be large. In analogy to Proposition 2, this has a negative impact on innovation. Conditions for the optimality of staying small are stated in Appendix A.

Proposition 4 *If the benefit of staying small and avoiding head-on competition with the incumbent dominates, the innovator is more likely to abandon the new technology. This has a negative impact on innovation.*

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

Corollary 2 *Imposing a cost of public ownership makes it more likely that the innovator chooses to remain small rather than growing large and choosing public ownership to soften head-to-head competition with the incumbent. Innovation in private firms suffers as a result.*

4.2 Coordination Through Equity Stakes

Suppose that the incumbent buys a non-controlling stake β in the innovator, which gives him a proportional right to the firm's cash flows, but otherwise no control rights.[19] 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, when both firms use the same technology, collusion can be achieved (provided that the incumbent's cash flows can also be observed by the innovator). The implications for whether it is optimal to seek coordination through equity stakes and how that interacts with innovation considerations are similar to those in Proposition 3. Specifically, coordination opportunities can lead to time-inconsistency problems, which would be particularly problematic when innovation is intermediately attractive.

The main difference to public ownership, when it comes to the effects of coordination on innovation, is that taking equity stakes would have negative effects on the incumbent's innovation incentives. If the innovator engages in the new technology, the incumbent benefits from it via its equity stake, which lowers its own incentives to innovate. This negative effect is stronger, the larger the incumbent's stake.[20] If the incumbent buys a controlling stake, coordination becomes automatic. Similar to Phillips and Zhdanov (2013), this scenario would feature a natural specialization in which the incumbent firm's incentives to innovate are even lower, while those of the innovator are higher compared to when the firms operate independently.[21] Summarizing, coordination through both equity stakes and through public ownership could lead to abandoning innovation too easily as described in Propositions 2 and 3. However, buying equity stakes has additional effects on innovation:

[19] Coordination and influence through minority equity stakes is particularly wide-spread in continental Europe and East Asia (see La Porta et al., 1999; Claessens et al., 2000).

[20] Observe that little changes for the innovator. The continuation decision is the same, and the R&D team is offered the same incentives.

[21] 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 competition issues are no longer relevant, the two firms will not compete away the first-mover profits on the new technology. What is more, since the opportunity cost of abandoning the new technology in order to collude on the existing one is also no longer present, the innovator can keep developing the new technology even after observing signal θ_M. The latter two effects increase the likelihood that the innovator develops the new technology.

Proposition 5 *(i) As with public ownership, buying a non-controlling equity stake in the innovator can help achieve collusion on the existing technology and can lead to time-inconsistency problems related to abandoning innovation too easily. However, coordinating through equity stakes has an additional negative effect on the incumbent's innovation incentives. (ii) Buying a controlling equity stake reduces the incumbent's innovation incentives even more, but it increases the likelihood that the innovator develops the new technology.*

Though buying equity stakes and public ownership are not perfect substitutes, it can be expected that imposing additional (e.g., regulatory) costs on public ownership would make buying equity stakes as an alternative means of achieving coordination more attractive.

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

Acquisitions would be an attractive alternative only up to a point, however. The reason is that, by reducing the number of players, acquisitions may face antitrust hurdles and would ease the tacit coordination opportunities facilitated by public ownership. Both of these effects would increase again the attractiveness of public ownership for coordination purposes. We return to this observation in Section 5, in which we discuss the empirical implications of our model.

4.3 Private Ownership and Voluntary Reporting

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

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

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 signal 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 that the private firm's signal is c and colludes, and with with probability η, it infers that the private firm's signal is nc and does not collude. Hence, the private firm's payoff from colluding in period two is $(1-\eta)\, x_C + \eta\,(x_C - m)$, while from not colluding $(1-\eta)\, bx_{NC} + \eta x_{NC}$. Two insights follow immediately. First in both cases, the private firm's period-two payoff increases from adding noise to its report when its cash flows are low. This is because, the private firm benefits when its counterpart behaves cooperatively regardless of whether it intends to deviate from collusion. Thus, following low cash flows in period one, the private firm will choose to add the maximum noise to its report $\eta = \underline{\eta}$. Second, comparing the payoffs of colluding and not colluding again in period two, colluding is ex post beneficial if

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

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

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

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

5 Empirical Implications

In this section, we summarize the empirical implication of our model. In Appendix B, we discuss some tentative empirical evidence from antitrust lawsuits showing that, consistent with our notion that public ownership facilitates collusion, public firms are several times more likely to be involved in antitrust lawsuits than comparable private firms.

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. Reasons for going public discussed in the literature include improving diversification opportunities and liquidity, raising capital for investment, exploiting favorable market conditions, facilitating acquisitions, and making the firm more visible (Ritter and Welch, 2002). We add one more reason for why a firm at a turning point in its life-cycle may seek public ownership, which is surprisingly neglected in prior work: facilitating collusion and coordination of strategies to avoid head-to-head competition (Proposition 1). This effect should be especially pronounced in concentrated industries with higher barriers to entry.

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

What speaks in favor of private ownership, however, is that it could help overcome the time-inconsistency problem associated with the long-term pursuit of innovation. Our new angle is that, by making it harder to coordinate on existing technologies, private ownership reduces the temptation to abandon the development of a new technology in case of early difficulties (Proposition 2).

Implication 2 *By making it more difficult to coordinate with rivals on existing technologies, private ownership helps firms resist the temptation to abandon the development of new ones in the face of early difficulties.*

Based on Implications 1 and 2, we can now describe which firms are more likely to prefer public ownership. A first group are firms for which preserving high margins on an existing technology is key, while further disruptive innovation is of secondary importance. As discussed in the Introduction, this would be relevant for firms in industries with stable technologies. It could also be relevant for firms with established business models that have turned into cash cows whose profit margins are worth preserving. Similarly, the coordination with public ownership might be important for firms in declining industries that may benefit from consolidation, but might face antitrust obstacles. We stress that, in such cases, prices and profits may well be falling, but coordination would help dampen the speed at which they fall and would help existing players keep market share.

Second, the potential for coordination with rivals is valuable also when firms simultaneously try to develop a new technology. High-tech firms going after the "next big thing" would be a typical example. Moreover, such firms may be working on a sequence of innovations, and may benefit from repeated coordination on new technologies. Coordination would also be valuable if it leads firms to focus their R&D resources towards developing different applications or aspects of a new technology. Indeed, as we have stressed, our notion of collusion encompasses more broadly also seemingly legal strategies that help firms to avoid competing head-on. These insights could shed light on puzzling stylized facts, such as why profit margins in public tech, biotech, and pharma firms are hard to square with competitive product markets and, more generally, why stricter disclosure standards for public firms have coincided with signs of a secular decrease in competition among public firms (De Loecker and Eeckhout, 2017).[22]

In light of these considerations, private ownership will be unambiguously better only when the innovation's expected profitability is intermediate, so that the innovator innovates alone and potentially seeks to avoid drawing the attention of incumbents to the new technology or delay the entry of new competitors. We expect this to be more likely for more-specialized firms or niche players still facing less immediate competition from rivals or for firms operating

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

in industries where rivals are less drawn to innovation, as it is unlikely to be disruptive. Indeed, consistent with our predictions, Bowen et al. (2018) find that VC-backed startups are more likely to go public if their technology is more disruptive and vice versa. Summarizing:

Implication 3 *The coordination benefit of public ownership is likely to dominate (i) if maintaining high margins on existing technologies is crucial, while innovation is of secondary importance; or (ii) if innovation is expected to have a first-order effect on profits both for the firm and its rivals. Then, the innovator could benefit from coordinating with firms that are also likely to develop the new technology. For intermediately attractive innovation that attracts less interest by incumbents, private ownership is more beneficial.*

The predicted U-shaped relation in Implication 3 could shed light on the mixed empirical evidence that suggests that public firms may appear both leaders and laggards in innovation. On the positive side, a simple look at Kogan et al.'s (2017) dataset reveals that about 40% of patents produced in the 40 years between 1970–2010 are by public firms, and for every year of issue, the mean and median citations of patents by public firms are higher than those by non-public entities. Indeed, Acharya and Xu (2017) find that public firms are more innovative (though they attribute this to public firms' better access to capital) and Feldman et al. (2018) find that public firms invest more in R&D than comparable private firms. On the negative side, Gao et al. (2018) find that public firms may engage less in explorative innovation. Bernstein (2015) provides a mixed picture by documenting that public firms tend to substitute internal for acquiring external innovation. Our predicted U-shaped relation reconciles such contradictory findings not only by explaining why some public firms may appear less, while others more, innovative, but also by highlighting that if a new technology is expected to be highly profitable, public ownership could encourage innovation by allowing firms to coordinate on that technology.[23] In the spirit of the old idea that monopoly profits can help spur innovation, Proposition 3 further predicts that, by helping firms avoid competition, public ownership could improve innovation incentives. In particular, when innovation opportunities are attractive, coordination facilitated by public ownership could potentially reinforce their profitability.

[23] Our paper has nothing to say about when collusion is going to be considered illegal by antitrust authorities. However, it is interesting to note that collusion on existing technologies is typically looked at more negatively than collusion on new technologies. An explanation could be that new technologies offer a surplus that could be shared and still leave consumers better off. See also "The Tech Antitrust Paradox" (The Economist, November 17. 2018)

Implication 4 *By allowing firms to maintain higher margins when simultaneously developing new technologies, public ownership could sharpen the incentives to innovate.*

Our model highlights the value of commitment when it comes to disclosing information. The difference between public and private ownership is an important novel application of this idea. However, it should be noted that recent advances in information technology have made it easier for private firms to disseminate valuable information about themselves to outsiders. With advances in new technologies, such as the blockchain, that further improve the verifiability of information, we expect that collusion opportunities may become easier also for private firms (Proposition 6) — a prediction shared also by Cong and He (2018).[24] This would negatively affect competition.

Implication 5 *Advances in information technology that ease the credible dissemination of information would improve coordination and collusion prospects under private ownership, which would allow private firms to retain high margins without going public.*

Public ownership is one important way to help firms commit to reporting regularly information about themselves regardless of whether it is in their best interest ex post. However, as noted in Section 3.3, we could reformulate Propositions 1-3 as a firm choosing between being a member of an industry association collecting price and quantity data from members and making these data available to members. Somewhat ironically, firms could also coordinate their prices when their products and services are tracked by price comparison websites. Our predictions for how innovation considerations will interact with such coordination opportunities are likely to apply also to these cases.

Finally, we comment briefly on what effects we anticipate from exogenous increases in the cost of public ownership, looking through the prism of our model. In doing so, we relate to recent empirical work that has argued that an increase in information disclosure requirements and compliance costs can only partially explain the decrease of public ownership in the U.S. In particular, it has been pointed out that the decline of public ownership coincides with an increase in merger and acquisition activity (Doidge et al., 2017). The latter is interesting, as it suggests that firms may be shifting from one way of achieving coordination to another

[24] 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.

(Corollary 3). Having said that, it should be pointed out that the resulting higher industry concentration would make tacit collusion easier to sustain among the remaining firms.

Implication 6 *An increase in the cost of public ownership will increase the propensity of firms to buy equity stakes or acquire firms as an alternative coordination mechanism to public ownership. The resulting higher industry concentration would increase the ease with which the remaining public firms can coordinate.*

Finally, based on Proposition 4, we expect that the cost of public ownership will affect the dynamics of smaller innovative firms. In particular, the reduced ability to go public and coordinate with rivals could lead innovative firms to stay small to avoid triggering head-to-head competition from incumbents. This would dampen innovation incentives (Corollary 2).

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

6 Conclusion

We develop a model that shows that the transparency that comes with public ownership helps facilitate the avoidance of competition. Such avoidance does not need to point at illegal types of collusion (leading to antitrust concerns), but could involve perfectly legal strategies. Avoiding competition is arguably one of the main focuses of the strategy literature, and a legitimate objective of running businesses. For firms, such strategies can be particularly valuable if they help preserve high margins on existing (commoditized) technologies.

However, by facilitating coordination on existing technologies and making them more profitable, public ownership could lead to the premature abandonment of new ones in case of early difficulties. That is, the existing technology becomes an attractive exit option. In light of this, the advantage of private ownership is that it helps as a commitment device for the long-term pursuit of innovation.

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 existing 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 might dominate again, as it could help firms coordinate on the new technology if they develop it simultaneously.

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

We discuss extensively the empirical implications of our model and point to supportive evidence from antitrust lawsuits for our basic premise that public ownership facilitates collusion. 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).

References

[1] Acharya, Viral, and Zhaoxia Xu, 2017, Financial dependence and innovation: the case of public versus private firms, *Journal of Financial Economics* 124(2), 223–243.

[2] Adams, Renee .B., Heitor Almeida, and Daniel Ferreira, 2009, Understanding the relationship between founder-CEOs and firm performance, *Journal of Empirical Finance* 16(1), 136–150.

[3] Allen, Franklin, and Douglas Gale, 1999, Diversity of opinion and financing of new technologies, *Journal of Financial Intermediation* 8(1–2), 68–89.

[4] Arrow, Kenneth J., 1962, Economic welfare and the allocation of resources to invention, In R.R. Nelson (Ed.), The rate and direction of economic activity, Princeton University Press, New York.

[5] Bernstein, Shai, 2015, Does going public affect innovation?, *Journal of Finance* 70(4), 1365–1403.

[6] Bhaskar, V., and Eric van Damme, 2001, Moral hazard and private monitoring, *Journal of Economic Theory* 102(1), 16–39.

[7] Bhattacharya, Sudipto, and Gabriella Chiesa, 1995, Proprietary information, financial intermediation, and research incentives, *Journal of Financial Intermediation* 4(4), 328–357.

[8] Bhattacharya, Sudipto, and Jay R. Ritter, 1983, Innovation and communication: signaling with partial disclosure, *Review of Economic Studies* 50(2), 331–346.

[9] Boot, Arnoud W. A., Radhakrishnan Gopalan, and Anjan V. Thakor, 2006, The entrepreneur's choice between private and public ownership, *Journal of Finance* 61(2), 803–836.

[10] Bowen, Donald E., Laurent Fresard, and Gerard Hoberg, 2018, Technological disruptiveness and the evolution of IPOs and sell-outs, Working Paper, Virginia Tech, University of Maryland, and University of Souther California.

[11] Bourveau, Thomas, Guoman She, and Alminas Zaldokas, 2017, Naughty firms, noisy disclosure: the effects of cartel enforcement on corporate disclosure, Working Paper, Hong Kong University of Science and Technology.

[12] Chang, Myong-Hun, The effects of product differentiation on collusive pricing, *International Journal of Industrial Organization* 9(3), 453–469.

[13] Chod, Jiri, and Evgeny Lyandres, 2011, Strategic IPOs and product market competition, *Journal of Financial Economics* 100, 45–67.

[14] Claessens, Stijn, Simeon Djankov, and Larry H.P. Lang, 2000, The separation of ownership and control in East Asian corporations, *Journal of Financial Economics* 58(1–2), 81–112.

[15] Cong, Lin Willian, and Zhiguo He, 2018, Blockchain disruption and smart contracts, Working Paper, University of Chicago.

[16] Dasgupta, Partha, and Joseph E. Stiglitz, 1980, Industrial structure and the nature of innovative activity, *Economic Journal* 90, 266–293.

[17] Denis, Diane K., and John J. McConnell, 2003, International corporate governance, *Journal of Financial and Quantitative Analysis* 38(1), 1–36.

[18] De Loecker, Jan, and Jan Eeckhout, 2017, The rise of market power and the macroeconomic implications, NBER Working Paper 23687.

[19] Doidge, Craig, G. Andrew Karolyi, and Rene M. Stulz, 2017, The U.S. listing gap, *Journal of Financial Economics*, 123(3), 464–487.

[20] Feldman, Naomi, Laura Kawano, Elena Patel, Nirupama Rao, Michael Stevens, and Jesse Edgerton, 2018, The long and the short of it: do public and private firms invest differently? Working Paper, Federal Reserve Board.

[21] Ferreira, Daniel, Gustavo Manso, and Andre C. Silva, 2014, Incentives to innovate and the decision to go public or private, *Review of Financial Studies* 27(1), 256–300.

[22] Fulghieri, Paolo, and Merih Sevilir, 2011, Mergers, spinoffs, and employee incentives, *Review of Financial Studies* 24(7), 2207–2241.

[23] Gao, Huasheng, Po-Hsuan Hsu, and Kai Li, 2018, Innovation strategy of private firms, *Journal of Financial and Quantitative Analysis* 53(1), 1–32.

[24] Gao, Xiaohui, Jay R. Ritter, and Zhongyan Zhu, 2013, Where have all the IPOs gone?, *Journal of Financial and Quantitative Analysis* 48(6), 1663–1692.

[25] Gilbert, Richard, and David Newbery, 1982, Preemptive patenting and the persistence of monopoly, *American Economic Review* 72(2), 514–526.

[26] Gilbert, Richard, 2006, Looking for Mr. Schumpeter: where are we in the competition-innovation debate?, in *Innovation Policy and the Economy*, Volume 6, edited by Adam B. Jaffe, Josh Lerner and Scott Stern, MIT Press, Cambridge Massachusetts.

[27] Green, Edward J., and Robert H. Porter, 1984, Noncooperative collusion under imperfect price information, *Econometrica* 52(1), 87–100.

[28] Greenstein, Shane, and Garey Ramey, 1998, Market structure, innovation and vertical product differentiation, *International Journal of Industrial Organization* 16(3), 285–311.

[29] Grossman, Gene M., and Elhanan Helpman, 1990, *American Economic Review, Papers and Proceedings* 80(2), 86–91.

[30] Grossman, Sanford J., and Joseph E. Stiglitz, 1980, On the impossibility of informationally efficient markets, *American Economic Review* 70(3), 393–408.

[31] Harrington, Joseph, 2008, Detecting Cartels, in Handbook in Antitrust Economics, Paolo Buccirossi, editor, MIT Press, Cambridge Massachusetts.

[32] Harris, Chris, and John Vickers, 1985, Perfect equilibrium in a model of a race, *Review of Economic Studies* 52(2), 193–209.

[33] Hatfield, John W., Scott D. Kominers, Richard Lowery, and Jordan M. Barry, 2018, Collusion in markets with syndication, Working Paper University of Texas at Austin.

[34] Kang, Ari, and Richard Lowery, 2014, The pricing of IPO services and issues: theory and estimation, Review of Corporate Finance Studies 2(2), 188–234.

[35] Kogan, Leonid, Dimitris Papanikolaou, Amit Seru, and Noah Stoffman, 2017, Technological innovation, resource allocation, and growth, *Quarterly Journal of Economics* 132(2), 665–712.

[36] Kultti, Klaus, Tuomas Takalo, and Juuso Toikka, 2007, Secrecy versus patenting, *RAND Journal of Economics* 38(1), 22–42.

[37] La Porta, Rafael, Florencio Lopez-De-Silanes, and Andrei Shleifer, 1999, Corporate ownership around the world, *Journal of Finance* 54(2), 471–517.

[38] Maksimovic, Vojislav, and Pegaret Pichler, 2001, Technological innovation and initial public offerings, *Review of Financial Studies* 14(2), 459–494.

[39] Matthews, Richmond D., 2006, Strategic alliances, equity stakes, and entry deterrence, *Journal of Financial Economics* 80(1), 35–79.

[40] OECD, 2012, Unilateral disclosure of information with anticompetitive effects, Competition Policy Roundtables.

[41] Pagano, Marco, Fabio Panetta, and Luigi Zingales, 1998, Why do companies go public? An empirical analysis, *Journal of Finance* 53(1), 27–64.

[42] Phillips, Gordon, and Alexey Zhdanov, 2013, R&D and the incentives from merger and acquisition activity, *Review of Financial Studies* 26(1), 34–78.

[43] Ritter, Jay R., and Ivo Welch, 2002, *A review of IPO activity, pricing, and allocations, Journal of Finance* 57(4), 1795–1828.

[44] Romer, Paul, 1990, Endogenous technological change, *Journal of Political Economy* 98(5), 71–102.

[45] Ross, Thomas W., 1992, Cartel stability and product differentiation, *International Journal of Industrial Organization* 10(1), 1–13.

[46] Schumpeter, Joseph A, 1934, The theory of economic development, Harvard University Press, Cambridge Massachusetts.

[47] Schumpeter, Joseph A, 1942, Capitalism, socialism, and democracy, Harper and Brothers, New York.

[48] Stein, Jeremy C., 1989, Efficient capital markets, inefficient firms: a model of myopic corporate behavior, *Quarterly Journal of Economics* 104(4), 655–669.

[49] Steuer, Richard M., John Roberti, and Daniel Jones, 2011, The application of antitrust to public companies' disclosures, *Administrative Law Review* 63(1), 159–180.

[50] Werden, Gregory J., 2004, Economic evidence on the existence of collusion: reconciling antitrust law with oligopoly theory, Antitrust Law Journal 71, 719–799.

[51] Wooldridge, Jeffrey M., 2002, Econometric analysis of cross section and panel data. MIT Press, Cambridge, MA.

Appendix A Proofs

Proof of Proposition 1. The proof shows that supporting collusion under private ownership is feasible only if signals are sufficiently correlated. Let $\{C_i, NC_i\}$ and $\{c_i, nc_i\}$ denote firm i's actions and signals in period one. As argued in the main text, firm 1 prefers to collude after observing signal c_1 (compared to deviating to non-collusion) if

$$\begin{aligned} & \Pr(c_2|C_1,C_2,c_1)x_C + (1-\Pr(c_2|C_1,C_2,c_1))(x_C - m) \\ > \; & \Pr(c_2|C_1,C_2,c_1)bx_{NC} + (1-\Pr(c_2|C_1,C_2,c_1))\, x_{NC} \end{aligned} \tag{A.1}$$

and prefers not to collude after observing signal nc_1 if

$$\begin{aligned} & \Pr(c_2|C_1,C_2,nc_1)x_C + (1-\Pr(c_2|C_1,C_2,nc_1))(x_C - m) \\ < \; & \Pr(c_2|C_1,C_2,nc_1)bx_{NC} + (1-\Pr(c_2|C_1,C_2,nc_1))\, x_{NC}. \end{aligned} \tag{A.2}$$

Note that without signal correlation, $\Pr(c_2|C_1,C_2,c_1) = \Pr(c_2|C_1,C_2,nc_1)$ and both conditions cannot be satisfied simultaneously.

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

$$\begin{aligned} 0 \;\le\; & x_C - K + \Pr(c_1,c_2|C_1,C_2)x_C + (1-\Pr(c_1,c_2|C_1,C_2))\, x_{NC} \\ & - \left(bx_{NC} + \Pr(c_1,c_2|NC_1,C)\, bx_{NC} + (1-\Pr(c_1,c_2|NC_1,C))\, x_{NC}\right). \end{aligned} \tag{A.3}$$

Omitting the details, it is straightforward to show that satisfying conditions (A.1)–(A.3) is possible if the signal correlations is sufficiently strong and the inference errors are sufficiently small, as in this case it can be achieved that $\Pr(c_2|C_1,C_2,c_1)$ and $\Pr(c_1,c_2|C_1,C_2)$ are sufficiently high, while $\Pr(c_2|C_1,C_2,nc_1)$ and $\Pr(c_1,c_2|NC_1,C)$ are sufficiently low. **Q.E.D.**

Proof of Proposition 2. Define y_C to be the innovator's two-period payoff when both firms use the same 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 if the continuation decision differs for $\theta = \theta_M$. Suppose, therefore, that $\theta_G x_M > y_C > \theta_M x_M > y_{NC}$ (note that there can be no single-period collusion on the new technology in period two). We treat the remaining cases at the end of the proof. In what follows, we consider in turn public (collusion) and private (non-collusion) ownership. Observe that the R&D team's wage cannot be made contingent on θ, as θ 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 θ_M if $y_C - w_A > \theta_M (x_M - w)$. Since $y_C > \theta_M x_M$, 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[25]

$$
\begin{aligned}
&(1 - p_M - \tau_M - p_G - \tau_G)(y_C - w_A) + (p_M + \tau_M)(y_C - w_A) \\
&+ (p_G + \tau_G)\,\theta_G (x_M - w)
\end{aligned}
\tag{A.4}
$$

subject to the R&D team's incentive constraint

$$
-(\tau_G + \tau_M)\,w_A + \tau_M w_A + \tau_G \theta_G w \geq c. \tag{A.5}
$$

It is optimal to set $w_A = 0$, since it relaxes (A.5), while increasing (A.4). Hence, $\theta_G w = \frac{c}{\tau_G}$, and the innovator's expected payoff becomes

$$
(1 - p_M - \tau_M - p_G - \tau_G)\,y_C + (p_M + \tau_M)\,y_C + (p_G + \tau_G)\,\theta_G x_M - \frac{(p_G + \tau_G)}{\tau_G} c. \tag{A.6}
$$

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

$$
-(\tau_G + \tau_M)\,w_A + (\tau_M \theta_M + \tau_G \theta_G)\,w \geq c. \tag{A.7}
$$

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

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

payoff is

$$\begin{aligned}&(1-p_M-\tau_M-p_G-\tau_G)\,y_{NC}+(p_M+\tau_M)\,\theta_M x_M\\&+(p_G+\tau_G)\,\theta_G x_M-\frac{(p_G+\tau_G)\,\theta_G+(p_M+\tau_M)\,\theta_M}{\tau_G\theta_G+\tau_M\theta_M}c.\end{aligned}\tag{A.8}$$

The condition that the innovation is continued if the innovator observes θ_M is

$$\theta_M x_M-y_{NC}>\theta_M w=\frac{\theta_M c}{\tau_G\theta_G+\tau_M\theta_M}.\tag{A.9}$$

If the inequality in (A.9) is not satisfied, the innovator does not have the right incentives at $t=0.5$ to take the efficient continuation decision. This creates scope for renegotiations, in which the R&D team extracts γ of the additionally generated surplus. Denoting the R&D team's payoff in that case with w_R, we have

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

In this case, the R&D team's incentive constraint at the contracting date $t=0$ becomes

$$-(\tau_G+\tau_M)\,w_A+\tau_M\,(w_A+\gamma\,(\theta_M x_M-y_{NC}))+\tau_G\theta_G w\geq c.\tag{A.10}$$

It is optimal to set $w_A=0$ and $w=\frac{c-\tau_M\gamma(\theta_M x_M-y_{NC})}{\tau_G\theta_G}$.[26] The innovator's expected payoff is then

$$\begin{aligned}&(1-p_M-\tau_M-p_G-\tau_G)\,y_{NC}+(p_M+\tau_M)\,(\theta_M x_M-\gamma\,(\theta_M x_M-y_{NC}))\\&+(p_G+\tau_G)\left(\theta_G x_M-\theta_G\frac{c-\tau_M\gamma\,(\theta_M x_M-y_{NC})}{\tau_G\theta_G}\right)\\=\;&(1-p_M-\tau_M-p_G-\tau_G)\,y_{NC}+(p_M+\tau_M)\,\theta_M x_M\\&+(p_G+\tau_G)\,\theta_G x_M+\gamma\,(\theta_M x_M-y_{NC})\left(\frac{\tau_M}{\tau_G}p_G-p_M\right)-\frac{(p_G+\tau_G)}{\tau_G}c.\end{aligned}\tag{A.11}$$

[26] Note that, if condition (A.9) is not satisfied, renegotiations in $t=0.5$ are, indeed, needed as

$$\theta_M x_M-y_{NC}-\theta_M\frac{c-\tau_M\gamma\,(\theta_M x_M-y_{NC})}{\tau_G\theta_G}=\left(1+\theta_M\frac{\gamma\tau_M}{\tau_G\theta_G}\right)(\theta_M x_M-y_{NC})-\theta_M\frac{c}{\tau_G\theta_G}<0.$$

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

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

if there are no renegotiations under non-collusion, and

$$(1-p_M-\tau_M-p_G-\tau_G)(y_C-y_{NC})+(p_M+\tau_M)(y_C-\theta_M x_M)-\gamma(\theta_M x_M-y_{NC})\left(\frac{\tau_M}{\tau_G}p_G-p_M\right) \tag{A.13}$$

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 (A.9) is satisfied. Furthermore, both (A.12) and (A.13) decrease in p_M, p_G, and τ_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 becomes more attractive) in τ_M, p_M, and x_M.

Finally, note that if $\theta_M x_M > y_C$, the continuation decision is the same under public and private ownership, in which case public ownership dominates because of its coordination benefit. If $y_C > \theta_G x_M > y_{NC}$, public ownership dominates again, in which case the innovation is not even undertaken in $t=0$. **Q.E.D.**

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

$$\theta x_M + \frac{\theta_{Inc}}{1-\theta_{Inc}}\theta y_O < y_O. \tag{A.14}$$

Hence, the abandonment threshold is higher than without competition. In particular, since $\frac{\theta_{Inc}}{1-\theta_{Inc}}$ increases in θ_{Inc}, abandonment is ex post optimal if and only if $\theta_{Inc} \le \frac{y_O-\theta x_M}{y_O+\theta y_O-\theta x_M}$, with the right-hand side increasing in y_O and decreasing in θ. In turn, this implies that continuation is always ex post optimal even following signal θ_M if $\theta_{inc} \ge \widehat{\theta}_{Inc} \equiv \frac{y_C-\theta_M x_M}{y_C+\theta y_C-\theta_M x_M}$. In this case, private ownership has no commitment benefit over public ownership.

If $\theta_{inc} < \widehat{\theta}_{Inc}$, the analysis is analogous to Proposition 2. In what follows, we show that private ownership is optimal above a threshold for p_G by considering the case in which condition (A.14) holds for θ_M and y_C, but not for θ_M and y_{NC}, such that abandonment in state θ_M is optimal under public, but not under private ownership.[27] 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

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

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

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

Continuation after observing θ_M requires that

$$\left(1 - \theta_{Inc}\right)\theta_M x_M + \theta_{Inc}\theta_M y_{NC} - \left(1 - \theta_{Inc}\right) y_{NC} > \frac{\theta_M c}{\tau_G \theta_G + \tau_M \theta_M}. \tag{A.15}$$

[27] Public ownership dominates in all other cases, i.e., if the abandonment decision is the same under public and private ownership or if innovation would always be abandoned in case of public ownership.

Suppose, next, that the inequality in (A.15) is not satisfied. Then, the innovator does not have the right incentives at $t = 0.5$ to take the efficient decision to continue. This creates scope for renegotiations, in which the R&D team extracts γ of the additionally generated surplus $w_R := w_A + \gamma\left(\left(1-\theta_{Inc}\right)\theta_M x_M + \theta_{Inc}\theta_M y_{NC} - \left(1-\theta_{Inc}\right) y_{NC}\right)$. Hence, at the contracting stage $t = 0$, the R&D team's incentive constraint is

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

Hence, it is optimal to set $w_A = 0$ and $\left(1-\theta_{Inc}\right) w + \theta_{Inc} w_{comp} = \frac{c - \tau_M w_R}{\tau_G \theta_G}$.[28] The innovator's expected payoff is

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

Subtracting the innovator's payoff under non-collusion (private ownership) from that under collusion (public ownership), we obtain

$$\begin{aligned}&\left(1 - p_M - \tau_M - p_G - \tau_G\right)\left(1-\theta_{Inc}\right)\left(y_C - y_{NC}\right)\\ &+ \left(p_M + \tau_M\right)\left(\left(1-\theta_{Inc}\right) y_C - \left(1-\theta_{Inc}\right)\theta_M x_M - \theta_{Inc}\theta_M y_{NC}\right)\\ &+ \left(p_G + \tau_G\right)\theta_{Inc}\theta_G\left(y_C - y_{NC}\right) - c\theta_M \frac{\frac{\tau_M}{\tau_G} p_G - p_M}{\tau_G\theta_G + \tau_M\theta_M}\end{aligned} \tag{A.16}$$

if there are no renegotiations under non-collusion, and

$$\begin{aligned}&\left(1 - p_M - \tau_M - p_G - \tau_G\right)\left(1-\theta_{Inc}\right)\left(y_C - y_{NC}\right)\\ &+ \left(p_M + \tau_M\right)\left(\left(1-\theta_{Inc}\right) y_C - \left(1-\theta_{Inc}\right)\theta_M x_M - \theta_{Inc}\theta_M y_{NC}\right)\\ &+ \left(p_G + \tau_G\right)\theta_{Inc}\theta_G\left(y_C - y_{NC}\right) - \left(\frac{\tau_M}{\tau_G} p_G - p_M\right) w_R\end{aligned} \tag{A.17}$$

if there are renegotiations.

Let $\widehat{p}_G'\left(\theta_{Inc}\right)$ define the value for p_G at which (A.16) or, respectively, (A.17) is zero. To

[28] It is straightforward to verify that renegotiations are, indeed, required to bring down w to w_R at $t = 0.5$.

see when such a point exists, note that both (A.16) and (A.17) are positive for $p_G = \theta_{Inc} = 0$, implying that public ownership dominates for these parameter values. Furthermore, taking the partial of (A.16) with respect to p_G we have

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

and, respectively, of (A.17) with respect to p_G

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

Both of these partials are negative when evaluated at $\theta_{Inc} = 0$, implying that the attractiveness of public ownership decreases when p_G increases. Clearly, this corresponds to the case analyzed in Proposition 2 in which $\theta_{inc} = 0$.

To analyze the effects as θ_{Inc} increases beyond zero, recall that public ownership always dominates for $\theta_{Inc} \geq \widehat{\theta}_{Inc}$ (as defined in the beginning of the proof). Furthermore, taking the cross-partial of (A.16) with respect to p_G and θ_{Inc}, we obtain

$$\left(y_C - y_{NC}\right) + \theta_G\left(y_C - y_{NC}\right) > 0. \tag{A.18}$$

The positive sign of (A.18) implies that the decrease in attractiveness of public ownership for higher values of p_G is weaker for higher values of θ_{Inc}, implying that $\widehat{p}'_G\left(\theta_{Inc}\right)$ increases in θ_{inc}. If $\widehat{p}'_G\left(\theta_{Inc}\right)$ exceeds one, public ownership always dominates.

The same insight obtains if the cross partial of (A.17) with respect to p_G and θ_{Inc}

$$\left(y_C - y_{NC}\right) + \theta_G\left(y_C - y_{NC}\right) + \frac{\tau_M}{\tau_G}\gamma\left(\theta_M x_M - \left(1+\theta_M\right)y_{NC}\right), \tag{A.19}$$

is positive. If (A.19) is negative, $\widehat{p}'_G\left(\theta_{Inc}\right)$ decreases in θ_{inc}, but it remains true that for $\theta_{Inc} > \widehat{\theta}_{Inc}$, public ownership dominates. **Q.E.D.**

Proof of Proposition 4. Suppose that both firms adopt the same technology in periods one and two and that Assumption 2 is not satisfied for the incumbent. Since $2x_C - bx_{NC} > K$ and $x_C - m > x_{NC}$, playing C in both periods is a dominant strategy for the incumbent regardless of the action taken by the innovator. Thus, the innovator is indifferent between being public and private. The key effect is that the resulting higher expected payoff from abandoning innovation and adopting the incumbent technology at $t = 0.5$ makes abandonment more likely (Proposition 2).

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

In the first case, the innovator abandons the new technology following signal θ_M 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. A.6) if

$$\begin{aligned} & (1 - p_M - \tau_M - p_G - \tau_G)\, b y_{NC} + (p_M + \tau_M)\, b y_{NC} + (p_G + \tau_G)\, \theta_G x_M - \frac{(p_G + \tau_G)}{\tau_G} c \\ > \; & (1 - p_M - \tau_M - p_G - \tau_G)\, \varphi y_C + (p_M + \tau_M)\, \varphi y_C + (p_G + \tau_G)\, \theta_G \varphi x_M - \frac{(p_G + \tau_G)}{\tau_G} \end{aligned} \tag{A.20}$$

or if b is above a threshold $b_1(\varphi)$, defined by

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

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

Proof of Proposition 5. (i) Let θ_{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

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

Since $V^{Innov,no\ comp} > V^{Inov,comp}$, increasing β makes condition (A.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 θ_M . 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

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

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

Appendix B Public Ownership and Antitrust Lawsuits

In what follows, we present patterns in the data that are consistent with our predictions that public ownership may facilitate collusion and that there is a U-shaped relation between the attractiveness of innovation and the benefit of public ownership. We construct a sample of firms that have filed an initial registration statement for an IPO with the SEC (Form S-1) and then compare firms that have gone through with their IPO to firms that have chosen to withdraw their IPO filing (by submitting Form RW). The data on U.S. IPO filings and withdrawals comes from Thomson One's New Issues database from 1985 until 2017. As it is standard, we exclude financial firms (SIC codes 6000-6999), unit offers, closed-end funds, American depositary receipts, limited partnerships, special acquisition vehicles, and spin-offs. Financial information comes from Compustat, Thomson One, and from the S-1 filing forms. We have such data for approximately 70% of the firms.[29]

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.[30] We then manually match the defendants in these lawsuits to our IPO filings sample. To allow for

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

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

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.

Panel A of 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.

Results Testing our model's predictions faces two main empirical challenges. The first is finding comparable public and private firms. Comparing firms that complete to firms that withdraw their IPO has the advantage of comparing public to private firms at similar stages of their lifecycle. However, the decision to withdraw is still highly endogenous and ideally would need to be controlled for. The second challenge is finding evidence for collusive behavior. Antitrust lawsuits are an imperfect proxy that restricts attention to outright illegal avoidance of competition. Though such lawsuits could be indicative for the wider collusion possibilities that public ownership facilitates, ideally, we would like to test also for coordination of strategy that facilitates the avoidance of competition and is not considered illegal. Because of these concerns, we emphasize that the evidence we present in what follows is mainly meant to serve as a motivation for further more rigorous analysis about the relation between competition avoidance and public ownership.

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

$$\begin{aligned} IPO_i &= \alpha + \beta_1 \Delta Industry\ R\&D + \beta_2 \Delta Industry\ R\&D^2 + \beta_3 Industry\ R\&D + \beta_4 Industry\ R\&D^2 \\ &\quad + \gamma NASDAQ_i + \delta X_i + \nu_k + \mu_t + \varepsilon_i, \end{aligned} \tag{B.1}$$

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

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

where AT_i^{post} is a binary variable taking the value of one if the firm is involved in an antitrust lawsuit in the four years after the IPO filing; IPO_i takes the value of one if the firm goes through with its IPO; $Industry\ R\&D$ are the average industry R&D expenses relative to total assets at two digit SIC level, $\Delta Industry\ R\&D$ is the change in such expenses relative to the pre-filing year. These variables proxy for the attractiveness of innovation in the industry. The quadratic specifications considers non-linear effects, where the U-shaped prediction implies that β_1 and β_3 in equation (B.1) should be negative, while β_2 and β_4 positive. The control variables X account for whether there was an antitrust lawsuits in the four years prior to the IPO filing (AT_i^{pre}), size ($Log\ total\ assets$, adjusted to inflation), revenues ($Sales/assets$), profitability ($Net\ income/assets$). The regressions further contain industry fixed effects at the two digit SIC level and IPO filing year fixed effects.

Columns (1) and (2) in Panel B of Table 1 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.[31]

Column (3) in Panel B of Table 1 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.

Final Remarks Following Bernstein (2015), we can address to some extent the problem of finding comparable public and private firms. Specifically, using model (1) in Table 1, 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 (B.1). 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. The results from models (4) and (5) in Panel B of Table 1 show a strong statistically and economically significant impact of the instrumented IPO variable on the likelihood of an antitrust lawsuit.[32]

[31] The results are also robust to using industry averages weighted by total assets or sales.

[32] As in Bernstein, $NASDAQ$ appears to be a valid instrument for the likelihood that the IPO is completed with an F-statistic of the first stage of the 2-SLS has a value of 25. NASDAQ returns in the one year before

Finally, it is worth noting that as part of their S-1 filing, all firms in our sample (including those that withdraw) must publish current and historical audited financial statements. Thus, if financial statements help better detection by third parties, then antitrust lawsuits should increase for *all* firms in our sample in the year following the filing. However, this is not the case, as the increase in lawsuits only occurs in the third year of being public and is strongest in the fourth and fifth year.[33] This long lag also speaks against the idea of opportunistic lawsuits triggered by the IPO filing.

and after the filing have no such effect. Model (5) follows Wooldridge (2002, p. 623, procedure 18.1), explained in detail in Adams et al. (2009).

[33] Interestingly, though economic evidence (typically micro industry data about prices and quantities) can be instrumental for determining damages, it is neither a standard tool for detecting cartels (Harrington, 2008) nor sufficient for proving guilt, as there must be evidence of explicit coordination (Werden, 2004). Instead, detection typically relies on leniency provisions for whistle blowers.

Table 1: Panel A presents summary Statistics comparing firms that complete their IPO filings with firms that withdraw 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. *NASDAQ returns* are the two months NASDAQ returns following the IPO filing, *Total assets* are the total assets, adjusted to inflation (base year 1999). All variables are 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. Panel B presents the regression results. 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*. Model (3) shows OLS estimates. Model (4) presents the second stage of the 2SLS estimates in which *IPO* is instrumented with *NASDAQ returns*, and model (5) presents the third stage of Wooldridge's three-stage procedure (18.1). Robust t-statistics are reported in the parentheses. *, **, and *** indicate that the coefficient is statistically significant at the 10%, 5%, and 1% level, respectively.

Panel A:	Completed	Withdrawn			Completed	Withdrawn	
	Mean	Mean	Difference		Mean	Mean	Difference
AT case before filing	0.006	0.004	0.002	Sales/assets	1.074	1.186	-0.112***
AT case after filing	0.020	0.006	0.014***	Industry R&D	0.033	0.032	0.001
Total asssets	180.996	164.678	16.318	NASDAQ returns	0.025	-0.018	0.043***
Net income/assets	-0.265	-0.375	0.110***				

Panel B:	(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)			
∆ Industry R&D	-0.120***	-0.480***	0.015	0.029	0.024
	(-2.819)	(-2.656)	(0.859)	(1.559)	(1.324)
∆ Industry 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)
Firm level controls	Yes	Yes	Yes	Yes	Yes
Filing year & 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			