Collusion with Public and Private Ownership and Innovation

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Abstract

We argue that public ownership allows firms to coordinate/collude and engage in rent seeking on existing technologies. The prospect of such coordination enhances firm value, yet reduces commitment to developing new technologies. We find that public ownership may still dominate for innovative firms if the expected profitability of the new technology is relatively low or very high. For intermediate values, private ownership dominates. Innovation incentives further depend on whether incumbents seek coordination through acquiring controlling or non-controlling stakes, as well as the size of the innovative firms vis-à-vis the incumbent. Our analysis sheds light on the conflicting evidence relating public ownership and innovation, and links declines in public ownership to an increase in takeover activity.

Keywords: public and private ownership, innovation, coordination, collusion.
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1 Introduction

The demise of the public corporation has been widely trumpeted in the news and academic literature (Gao et al., 2013; Doidge et al., 2016). Fewer firms go public nowadays than they have done historically, and new firms delay longer their initial public offerings. One explanation that stands out is the plethora of regulation, information requirements, and public scrutiny faced by public firms, which could lead to leaking of valuable information to competitors (Bhattacharya and Ritter, 1984) or to pressures to focus on the current share price and behave myopically (Stein, 1989). Yet despite such arguments, public firms are profitable like never before, calling into question such concerns and gloomy projections.[1] If anything, the more relevant question seems to be why not more firms go public.

To add to the contradiction, the recent empirical literature has argued that private firms' innovation is more impactful (Bernstein, 2015). Such findings seem hard to reconcile with the fact that public firms, such as Amazon, Apple, and IBM, are at the forefront of innovation with the common belief that "Google is furthest along in quantum-computer technology and that Microsoft has the most comprehensive plan to make the software required."[2]

In this paper, we argue that a key argument in favor of public ownership is that the more transparent availability of information about a public firm's cash flows allows for better coordination among incumbents. Thus, new players go public when their technology is becoming a commodity and they seek coordination to maintain high margins.

The flipside of having the option to coordinate on existing technologies is that it could weaken incentives for innovation, as it makes it more difficult to commit not to abandon the development of a new technology in the face of early difficulties. This could lead to time-inconsistency problems not present under private ownership, and creates a trade-off between the option to coordinate and the ability to commit to long-term innovation. One of our main findings is that this trade-off leads to a U-shaped relation between the attractiveness of public ownership and the expected profitability of innovation, with private ownership dominating the middle ground—a finding that could shed light on the above contradictory evidence. By analyzing the role of controlling or non-controlling stakes as an alternative tool to achieve coordination, our model further shows that a decline in public ownership would go hand-in-hand with an increase in takeover activity, consistent with recent findings (Doidge et al., 2016).

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

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

To address these issues, we develop a model in which two firms, an innovative player ('the innovator') and an incumbent, operate in the same market. Our model has two main elements. First, in the initial period of the model, the innovator can start exploring a new technology, which requires hiring an R&D team. At an interim date of that period, the innovator obtains a signal indicating the new technology's profitability. At this point, exploration can be abandoned and the innovator can adopt the incumbent's technology. However, if the new technology is not abandoned and is successful, the innovator gets high returns. The second main element of our model is that, when both firms use the same technology, they might engage in tacit coordination (or collusion). What stands in the way of such coordination, however, is that each firm faces a type of prisoner's dilemma: Coordination over two periods is beneficial, but firms might have incentives to deviate since such deviations might be difficult to detect. This is because firms use their cash flows to draw signals about each other's actions, and these inferences are imperfect.

Our first main result is that public ownership helps in sustaining coordination when both firms use the same technology. The key difference between public and private ownership that we model is that the cash flows of public firms are observable to all, while those of private firms are not. This lack of transparency under private ownership has two implications. First, the firms draw noisier signals about each other's actions, making a breakdown in coordination due to wrong inferences more likely. Second, the threat to punish deviations might not be credible under private ownership, as firms have incentives to disregard their signals. This is because the signal that a firm infers from its own cash flow is only a noisy indicator of the other firm's actions. Thus, in a conjectured equilibrium in which firms are supposed to coordinate, a signal that the other firm has not coordinated can only be wrong. Specifically, if firm "A" coordinates, it expects that the most likely signal firm "B" receives is that it has coordinated. As a result, expecting a repeated coordination by firm B, firm A has an incentive to coordinate again *regardless* of its signal. But then firm B will benefit from never even starting to coordinate, making it impossible to sustain a coordination equilibrium. All of this changes under public ownership, as cash flows are then mutually observable, implying that firms observe each other's inferences. Thus, if one firm (correctly or not) infers that the other has not coordinated, this becomes common knowledge. Neglecting one's signal is now never optimal, as firms do not have to guess what the other firm will do. They know that a punishment to a non-coordinating equilibrium should follow, making it, indeed, mutually optimal to stop coordinating. Thus, punishments are credible and a coordination equilibrium can be sustained.

Our second main result is that securing the ability to coordinate might not be beneficial if the firm pursues innovation. The option to coordinate on a high-margin existing technology makes it more likely that the innovator abandons the development of the new technology in the face of a discouraging signal. This could lead to a time-inconsistency problem: abandonment becomes too likely, making it very expensive to motivate the R&D team to exert effort. Thus, public ownership leads to a trade-off between a higher cost of motivating effort and having a better abandonment option.

Which of these two effects dominates depends on the new technology's expected profitability. We show that, if that profitability is low, the innovator is better off under public ownership. In this case, the option to abandon the new technology in case of early difficulties and coordinate on the existing one is more valuable than the ability to motivate the R&D team at a lower cost. Things change if the new technology's expected profitability becomes sufficiently high. Then, the option to coordinate on the existing technology associated with public ownership becomes less important and what starts to matter more is the higher cost of motivating the R&D team. However, if the new technology's expected profitability is so high that also the incumbent decides to pursue it, such highly-profitable innovation opportunities are best developed in public firms. In this case, the incumbent and the innovator can substantially benefit from coordinating on the new technology if both firms successfully develop it. This leads to a U-shaped relation between the attractiveness of public ownership and the new technology's expected profitability.

An alternative way to achieve coordination is for the incumbent to buy an equity stake in the innovator. With a non-controlling stake, coordination is possible if the innovator can also observe the incumbent's cash flows. However, the downside is that it may reduce the incumbent's incentive to pursue the innovative project, as it can benefit from the innovator's innovation activities via its equity claim. A controlling stake further reduces the incumbent's innovation incentives, but it increases the innovator's incentives to pursue the new technology. The reason is that, being effectively in control of both technologies, the incumbent does not face the innovator's opportunity costs of prematurely abandoning the new technology. Thus, it will dictate that the new technology's development is kept alive even in the face of discouraging signals. Thus, coordination via being public or via equity stakes are partial substitutes. With less developed equity markets, we expect that coordinating through equity stakes is more prevalent. Furthermore, we expect that increases in the cost of public ownership will drive firms to seek more coordination through equity stakes. The latter prediction is line with recent evidence that the drop in IPO activity has been accompanied by an increase in M&A (Doidge et al., 2016).

The choice between public and private ownership is also affected by the relative size of the innovator and incumbent. If the innovator is much smaller, it can afford to chip away market share from the incumbent without fearing that the incumbent will retaliate over a small rival. As a consequence, smaller firms may be inclined to innovate less regardless of whether or not they are public, as the ability to adopt the incumbent's high-margin technology creates a more-pronounced time inconsistency problem of not being able to commit to the new technology. Finally, in an extension, we show that voluntary reporting by private firms does not help much in terms of achieving coordination, as absent exogenous strict reporting requirements, the private firm will have ex post incentives to add noise to its report, making coordination ultimately unsustainable

The question when firms prefer public and when private ownership has a long history in the finance literature. Our main contribution is to address this question from a novel angle by building on insights from the game theoretic literature that more transparency among competitors allows to support collusion (Green and Porter, 1984; Bhaskar and Van Damme, 2001). Indeed, the higher transparency in public firms is one of the text-book differences between public and private ownership, but the implications for coordination and how that affects innovation incentives in public and private firms have not been thoroughly explored in prior work. The corporate finance view seems to be that the higher transparency associated with public ownership is the cost that an innovative firm needs to pay for gaining access to cheaper financing (Bhattacharya and Ritter, 1984; Maksimovic and Pichler, 2001). The cheaper access to capital can help the firm invest in more innovation, especially if the firm gains access to investors who have more aligned beliefs with those of the firms' managers (Allen and Gale, 1999). The empirical evidence is supportive of such theories. Acharya and Xu (2016) find that public firms in external finance dependent industries spend more on innovation and have a better innovation profile than private firms, while the same is not true for internal finance dependent industries. We depart from this discussion, as financial constraints do not feature in our model. Furthermore, our notion of transparency is only that cash flows of public firms are publicly observable, and not that sensitive information becomes available to competitors.

One of the advantages of private ownership in our model is that it features more tolerance for failure, 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 differentiate our work from Ferreira et al. (2014) who argue that the lack of transparency with private financing could facilitate exit by early investors. In particular, the lack of transparency associated with private ownership prevents outside investors from inferring whether the true reason for exit is an illiquidity shock or that the firm's innovation has failed—somewhat reminiscent of Grossman and Stiglitz (1980). This makes early private investors more tolerant for failure in the sense that they are more likely to invest in risky innovations in the first place. There are no time inconsistency problems in Ferreira et al. (2014). Another key difference is that private ownership in their paper always dominates when exploring new ideas. By contrast, we show that, new ideas are better explored under public ownership if they are expected to be either very profitable or only sightly profitable. Private ownership dominates only for intermediate values for the new technology's profitability. Furthermore, we discuss the effect of equity stakes and the relative sizes of the firms involved for the ability to coordinate and how that affects innovation and the public-private choice. These different perspectives generate an interesting contrast in empirical predictions.

The U-shaped relationship between the attractiveness of public ownership and the new technology's profitability is also the main difference to the managerial myopia literature (Stein, 1989) in which public ownership creates time inconsistency due to a manager's focus on the current stock price. In our model, the reason for time inconsistency is that the firm undermines ex ante innovation incentives when it can fluently respond to interim signals on the new technology; this becomes particularly acute when it can coordinate on the existing technology, and thus faces an attractive exit option. A further difference is that in our model the ability to coordinate under public ownership is also valuable when firms compete to develop the new technology, as then they could coordinate not to eat into its other's profits if equally successful.

Our analysis relates also to the vast industrial organization literature analyzing whether market concentration is good for innovation. The conceptual difference in our paper is that we are not interested in the effect of competition on innovation per se,[3] but in the endogenous interaction between the choice of public and private ownership, buying equity stakes, and coordination and innovation incentives.[4] In particular, we argue that the firm's ownership structure determines whether or not its cash flows are observable to a competitor, which is of importance for coordination and innovation incentives. We show that such interactions could help explain stylized facts, such as why the recent decrease in public ownership coincides with increased takeover activity (Doidge et al., 2016).

Our paper continues as follows. Section 2 describes the baseline model. Sections 3–5

[3] The question whether competition is good for innovation goes back to Schumpeter (1934, 1942). Key factors are whether innovation focuses on processes that would have a similar advantage to all firms (Arrow, 1962) or products that could 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.

[4] Prior work shows that cross-ownership could reduce the need to compete (Reynolds and Snapp, 1986), may reduce innovation incentives (Matthews, 2006), or make collusion more difficult (Malueg, 1992).

contain our main results, extensions, and empirical implications, and Section 6 concludes. All proofs are in the Appendix.

2 Model

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

The technologies At $t = 0$, the innovator has access to two technologies—an innovative (new) technology and an incumbent (old) technology. Neither technology requires an initial investment, but the innovator has the capacity to choose only one. The new technology is risky. It is viable and returns positive cash flows with probability θ and is unviable, returning 0, with probability $1 - \theta$. This probability is unknown at date $t = 0$ when the technology choice is made. It is only commonly known that it can take on three values $\theta \in \{0, \theta_B, \theta_G\}$ where the ex ante probabilities of θ_B and θ_G are p_B and p_G, respectively, and where $0 < \theta_B < \theta_G$. At the interim date $t = 0.5$, an observable but not verifiable signal is realized that shows the value of θ. At this point in time, if the innovator has started the new technology, it can abandon it and switch to the incumbent technology. In either case, the first-period cash flows are realized only at the end of the period.

If the innovator decides to start the new technology, it needs to hire an R&D team. If the R&D team exerts effort, it can increase the likelihood of θ_B and θ_G to $p_B + \tau_B$ 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_B and θ_G unchanged at p_B and p_G), the R&D team can save a non-monetary cost c. We assume that the decision whether or not to abandon the new technology at $t = 1$ lies with the innovator, and not the R&D team.[5]

Unlike the innovator, the incumbent firm operates for sure the incumbent technology in period one. It can additionally try to develop the new technology itself, but this would require hiring the necessary R&D talent to generate the ideas behind the new technology. For our purposes, it is sufficient to assume that this is associated with a deadweight cost of k, and a likelihood of ρ that the new technology is successful. Regardless of who develops the new technology, it replaces the incumbent technology in period two if it is successfully developed.

If only one of the two parties successfully develops the new technology, it enjoys first-

[5] This emerges naturally if the realization of θ is the innovator's private information.

mover cash flows of x_{FM} for periods one and two, while the other firm's cash flows are zero in both periods. If none of the firms is successful in developing the new technology, and the innovator has pursued it until the end of period one, the incumbent reaps the monopoly profits x_M from the incumbent technology, while the innovator gets zero in both periods. If the new technology is abandoned or never undertaken in period one, both firms use the incumbent technology. If both firms use the same technology (either the new or the old one), coordination might come into play. Figure 1 summarizes the sequence of events.

Coordination Problem if Both Firms Use the Same Technology How does coordination work? In each period when using the same technology both firms decide whether to coordinate (action C) or not coordinate (action NC). The action affects the firms' cash flows, which are stochastic and realized at the end of the respective period. If both firms coordinate in a given period, their expected cash flows when utilizing the preferred (and available) technology in that period are x_C for each. If neither firm coordinates, their expected cash flows are $x_{NC} < x_C$. If one of the firms coordinates, 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 $b > 1$. Intuitively, one can think of this case as one firm setting high prices, while the other firm undercutting it and stealing market share.

A feature of the model is that in a one-shot game (single period) both firms face a prisoner's dilemma, making coordination over one period impossible. However, coordination is potentially possible in a two period setting. To facilitate this, we assume that firms face a (one-time) cost K the first time they seek coordination, but no such cost in the following period. We now let $x_C - K < bx_{NC}$. This means that in a one-period setting the prisoner's dilemma is acute: anticipating coordination by the other firm, makes choosing no coordination optimal. However, if coordination is chosen nonetheless, coordinating again in the following period yields $x_C > bx_{NC}$. Assuming in addition that $(x_C - K) + x_C > bx_{NC} + x_{NC}$ makes coordination over two periods potentially worth it. Summarizing:

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

These conditions are necessary (but not sufficient) that coordination is sustainable at least under some circumstances in a multi-period setting.[6] A final condition we need is that coordination (e.g., setting high prices) cannot be optimal for a firm if the other firm does not coordinate (sets lower prices). In that case not coordinating (also setting lower prices) makes the firm better off:

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

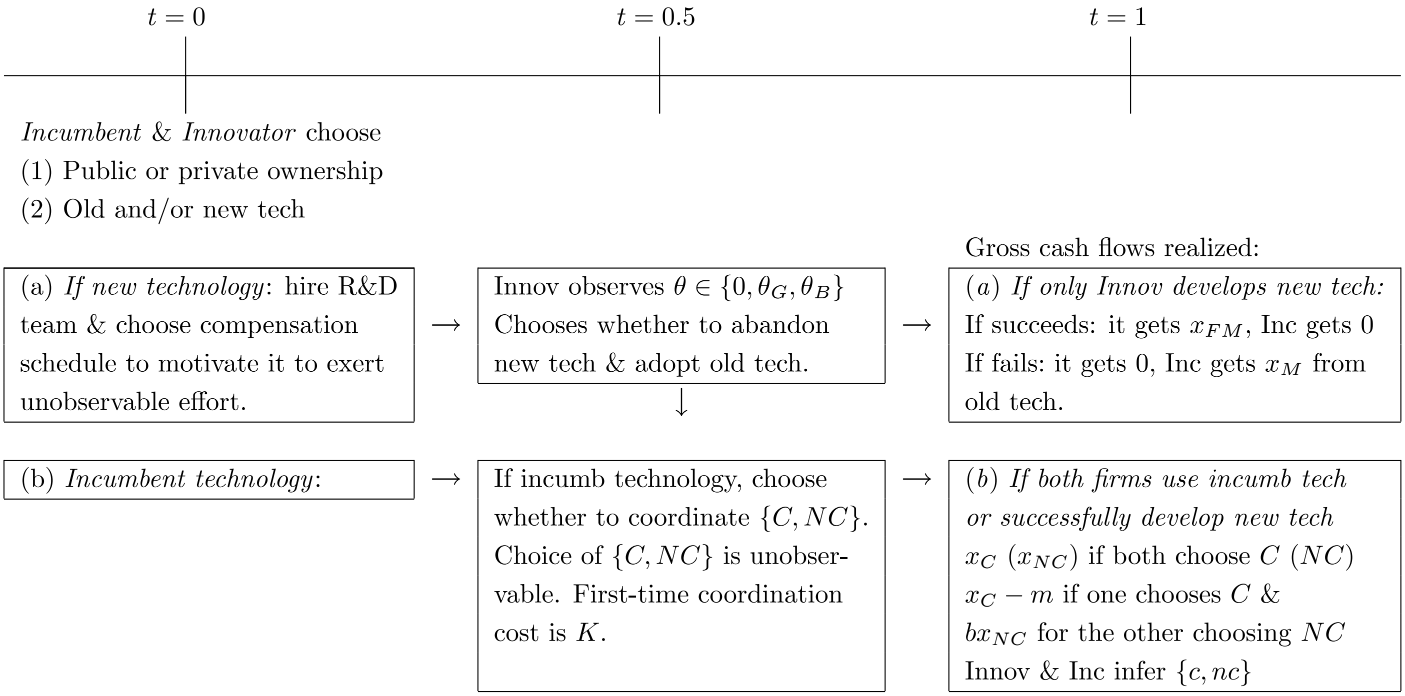

Figure 1: **Timeline of first period.**

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 relaxing this and allow for different sizes between the innovator and the incumbent.

Information Structure and Public vs. Private Ownership We assume that direct coordination between the firms is not feasible or (legally) possible. Actions are not observable, but at the end of every period, each firm observes its own cash flows, from which it extracts a signal $s = \{c, nc\}$ about whether or not the other firm has coordinated. Since cash flows are stochastic (x_C and x_{NC} are the *expected* values), the signal is noisy, and the inference is correct only with probability $1 - \varepsilon$.[7]

A critical difference between private and public ownership is that a public firm's cash flows are observable to the other firm. This implies that: (i) The signal a public firm extracts from its cash flows is observable to the other firm; (ii) The inference error ε (weakly) decreases, since the signal is based on *both* firms' cash flows. The decision whether the firm should be public or private is made at the beginning of the first period ($t = 0$). In

[7] At the expense of introducing additional notation, we could derive ε from primitivies using Bayes rule. However, this is not necessary for our purposes.

Section 4.3, we extend the model to allow a private firm to engage in voluntary reporting.

3 The Choice Between Public and Private Ownership

There are three main choices in this model: (i) whether firms that use the same technology will coordinate, (ii) whether the innovator abandons the new technology at $t = 0.5$ and (iii) whether the innovator is better off innovating under public or private ownership.

In what follows, we show that public ownership facilitates coordination on the incumbent technology. This could lead to a time inconsistency problem in which the innovator responds too aggressively (from an ex ante perspective) to unfavorable intermediate signals on the viability of the new technology, i.e., abandons it too often. We proceed as follows. First, we explain how coordination works and how it depends on being public or private. Subsequently, we focus on the time inconsistency problem and analyze when public or private ownership is preferred.

3.1 Public Ownership as a Coordination Mechanism

We start by analyzing the first choice. Both firms' cash flows are higher if they manage to coordinate. However, coordinating only in one period is not feasible. If one firm intends to coordinate, it is optimal for the other not to do so, as its expected cash flow from not coordinating, bx_{NC}, is higher than that from coordinating, $x_C - K$.

The key insight in what follows is that coordination can be sustained if both firms use the same technology for two periods, but this crucially depends on whether the firms choose public or private ownership. The choice of ownership affects two ingredients. First, it affects the inference error on whether the other firm has coordinated in the preceding period. Second, it affects what a firm learns about the other firm's signal.

Consider the following equilibrium candidate under private ownership: Both firms coordinate in period one, and coordinate in period two if and only if they infer from their cash flows that the other firm has coordinated as well (i.e., their signals are c).

Private ownership hampers coordination for two reasons. First, by increasing the inference error ε, it makes it less likely that coordination in period two can be sustained. For coordination in period two following signal c to be preferable to not coordinating, it must hold

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

This expression takes into account that even if a firm coordinates in period one, the other firm infers signal nc with probability ε, which prompts that firm not to coordinate in period two. Such punishment reduces the expected payoff from coordinating in both periods.[8]

The second reason is that a private firm that has coordinated in period one has incentives to coordinate also in the second period *regardless* of the signal it infers about the other firm's actions. This creates incentives for the other firm not to coordinate in both periods, making it impossible to sustain a coordination equilibrium.

To see why a private firm that has coordinated in the first period might ignore its signal and coordinate also in period two, consider the case of independent signals. Since both firms are supposed to coordinate in period one, they attribute signal nc to the inference error ε, as non-coordination is an out-of-equilibrium (i.e., zero probability) event. In particular, if a private firm coordinates in period one, it expects that the other firm receives signal c with probability $1 - \varepsilon$ and, thus, coordinates also in period two with such probability. Hence, regardless of its signal, the private firm's expected payoffs from coordinating and not coordinating in period two are the same as on the left- and right-hand side of expression (1), respectively. Hence, if the firm coordinates after inferring c, it has the same incentive to coordinate after inferring nc. Thus, it is individually optimal not to go through with the threat of not coordinating in that period. This is true for any inference error $\varepsilon > 0$.

This problem could be ameliorated if both firms' signals are dependent and if that dependence implies that the *conditional* likelihood $\widetilde{\varepsilon}$ after observing nc that also the other firm has inferred nc is higher than after signal c (in this case the inference error ε in (1) differs depending on whether the firm infers c or nc). Then, if $\widetilde{\varepsilon}$ is sufficiently high, the expected payoff from not coordinating in period two becomes higher than that from coordinating (as $x_C - m < x_{NC}$). Thus, not coordinating following signal nc becomes a credible threat.[9]

Public ownership circumvents the above two problems, as it makes both firms' signals mutually observable. Thus, the equilibrium candidate can be amended as: coordinate in the first period, and coordinate 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 coordinate in period two makes it, indeed, a mutual best response not coordinate in that period. The opposite holds if both firms observe signal c.[10] What further simplifies coordination is that the inference errors decrease, making the

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

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

[10] Observe that signal dependence is irrelevant for this argument. Furthermore, note that since signals

expected payoff from coordinating in both periods

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

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

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

Proposition 1 ***(Public ownership as a coordination mechanism):*** *(i) Public ownership facilitates coordination. (ii) Coordination cannot be achieved under private ownership if the firms' signals are independent. Coordination under private ownership is feasible only if signals are sufficiently correlated (i.e., one firm observing signal nc goes hand-in-hand with a higher likelihood that the other firm also observes nc), and the inference errors are sufficiently small.*

Corollary 1 *Firms go public if they are ready to join the incumbents and coordinate with them on a commoditized technology. Alternatively, firms go public if their own technology is becoming commoditized and they seek coordination on it.*

To avoid trivial cases, we assume in what follows that coordination is always achieved under public, but never under private ownership. Formally, this would be the case if $\varepsilon = 0$ under public ownership and if the signals are not (very) interdependent.

3.2 Private Ownership and Overcoming Time Inconsistency

Given the easier coordination and higher profits with public ownership, one might wonder why not all firms go public in our model. Our answer is that coordination might undermine innovation incentives. Choosing private ownership might then become a commitment mechanism. To make the point, suppose for now that only the innovator can develop the new technology (i.e., the incumbent's success likelihood is $\rho = 0$).

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

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.

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 $w_0 = 0$. In case the contract is renegotiated at $t = 0.5$, we denote the R&D team's bargaining power with γ.

The R&D team's incentive constraint is

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

where $U(\mathbf{w},\tau)$ denotes the R&D team's expected payoff if it exerts effort, and $U(\mathbf{w},0)$ is its expected payoff if it exerts no effort. Since, by optimality for the innovator, (2) will be satisfied with equality and the R&D team's outside option is zero, $U(\mathbf{w}, 0)$ represents the R&D team's agency rent. It is straightforward to show that it is optimal to pay the R&D team only if the new technology is continued (i.e., $w_A = 0$).

The tension between ex post optimality and ex ante incentives arises because the abandonment of the new technology in case of unfavorable θ realizations has two effects. One is the standard positive disciplining effect of not getting paid ($w_A = 0$) if the new technology is abandoned. The strength of this effect increases in the impact of effort (τ_G) on the likelihood of landing in state θ_G. However, the second effect is negative. In particular, exerting effort increases also the likelihood of state θ_B by τ_B. Since this effort is wasted in case the new technology is abandoned in state θ_B, such abandonment makes it more difficult to satisfy the R&D team's incentive constraint. This negative effect dominates if τ_B is sufficiently large (formally, if $\tau_B > \tau_G \frac{p_B}{p_G}$). Then, the better abandonment option in $t = 0.5$ under public ownership makes it more expensive to motivate the R&D team compared to private ownership.

The key insight is that the resulting time inconsistency problem of not being able to commit not to abandon the new technology in case of state θ_B could make private ownership preferable. This occurs if the ex ante expected profitability of the new technology is sufficiently high (i.e., p_G is high), as then then the innovator needs to pay the R&D team a higher wage (if $\tau_B > \tau_G \frac{p_B}{p_G}$), while benefiting less from the better coordination possibilities of public ownership in states $\theta = \{0, \theta_B\}$.

Proposition 2 ***(Time inconsistency and private ownership):*** *The inability to commit not to abandon the new technology in case of signal θ_B gives rise to a time inconsistency problem. At $t = 0$, such commitment would decrease the cost of hiring the R&D team, but sticking to this commitment at $t = 0.5$ might be infeasible if the innovator observes θ_B. (ii) There is a threshold for $\widehat{p}_G$, such that the innovator prefers private ownership if $p_G > \widehat{p}_G$, and public ownership otherwise.*

The second part of Proposition 2 states that, despite making it easier to overcome the time-inconsistency problem, private ownership is preferable only if the new technology is sufficiently attractive. This is because, if abandonment is very likely, the option to coordinate becomes more valuable. Clearly, if the innovator does not even initiate the new technology's development, public ownership is always preferable.

3.3 Competition for Innovation and the Public-Private Choice

Consider now the possibility that the incumbent also develops the new technology. The incumbent firm would do that if its success likelihood ρ is sufficiently high to compensate it for its investment costs k (we endogenize this decision in Section 4.2). Note that in this case, the incumbent firm would not abandon the new technology at $t = 0.5$, as it does not face the innovator's trade off between developing the new or adopting the old technology.

Competition on the new technology has two key effects. First, if both firms successfully develop the new technology, they can benefit from coordinating not to compete away each other's profits. Thus, coordination can have a positive effect on innovation, as it increases the reward in case of success. This effect becomes increasingly valuable for the innovator, the more likely it is that both firms successfully develop the new technology (i.e., if both p_G and ρ are high).

Second, competition makes it less likely that the innovator abandons thew new technology at $t = 0.5$, as it will make zero profit from the incumbent technology if the incumbent develops the new technology. If the incumbent's success likelihood ρ is sufficiently high, this effect could make the innovator's continuation decision under both public and private ownership the same. Specifically, if ρ is high, the coordination prospects are not sufficiently likely to warrant abandonment in states θ_B and θ_G under both ownership types. But when the continuation decision under both ownership types is the same, the cost of hiring and motivating an R&D team is the same, making the coordination benefits of public ownership more beneficial.

Proposition 3 ***(Competition for innovation)*** *Suppose that both firms compete to develop the new technology. (i) An advantage of public over private ownership is that both firms can coordinate in case they both successfully develop the new technology. This advantage can dominate the effects in Proposition 2 if p_G and ρ are high. (ii) There is a threshold $\widehat{\rho}$, such that the innovator does not abandon the new technology in states θ_B and θ_G under both ownership types, making public ownership preferable for $\rho > \widehat{\rho}$.*

Since in practice, ρ and p_G are likely to be correlated, assume for simplicity that $\rho = p_B\theta_B + p_G\theta_G + \delta$ (where δ could be positive or negative). Summarizing the results from this section, we obtain a U-shaped relationship between the attractiveness of innovation and that of public ownership:

Corollary 2 *The innovator's choice between public and private ownership is U-shaped in the new technology's profitability. If that profitability is:*
(i) low, it is optimal to choose public ownership;
(ii) medium, it is optimal to choose private ownership;
(iii) high, it is optimal to choose public ownership.

4 Equity Stakes, Size, and Coordination

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

4.1 Coordination Through Equity Stakes

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

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

If the incumbent buys a controlling stake, however, coordination issues are no longer present. This leads to 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. 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, absent coordination issues, 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 coordinate on the existing one is no longer present, the innovator can keep developing the new technology even after receiving signal θ_B. The latter two effects increase the likelihood that the innovator develops the new technology.

Proposition 4 *(i) Buying a non-controlling equity stake in the innovator can help achieve coordination on the existing technology, but it reduces the incumbent's innovation incentives. (ii) Buying a controlling equity stake further reduces the incumbent's innovation incentives, but it increases the likelihood that the innovator develops the new technology.*

Overall, the main insight from this section is that buying equity stakes can help achieve coordination, but affects innovation incentives, as such coordination via public ownership or equity stakes are not perfect substitutes. Nevertheless, one would expect that imposing additional (e.g., regulatory) costs on public ownership would make coordination through equity stakes more likely.

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

4.2 Size, Innovation, and Coordination

In this section, we extend our baseline model by introducing a date $t = -1$ at which the innovator can choose to operate at larger scale at no additional cost. Let φ be the scaling parameter, which increases expected profits to φx_{NC}, φx_C, and φx_{FM}. Since such scaling up does not affect the relative attractiveness of coordinating versus not coordinating, what is more important is how it affects the incumbent's profits. We assume that in case of non-coordination, the incumbent's profits fall by φm. Specifically, for the incumbent's cash flows, we assume that $x_C - \varphi m < x_{NC} < x_C - m$. That is, Assumption 2 is satisfied if the innovator is large, but not if it is small.

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

First, the innovator's choice between coordination and no coordination is the same under public and private ownership. Second, because the incumbent does not engage in price wars with the innovator, the innovator's incentives to abandon the new technology and adopt that of the incumbent are at least as high as those under public ownership in Proposition 1. Hence, its incentives to innovate are lower than those of the innovator, described in Section 3.2.

Proposition 5 *(i) If the innovator remains small, the incumbent takes action C regardless of the innovator's action. In this case, the innovator is more likely to abandon the new technology and is indifferent between public or private ownership. (ii) The innovator is better off remaining small if the impact of size on the incumbent's payoff, φm, is low relative to b or if the incumbent is not public or does not buy an equity stake in the innovator.*

An important consequence of Proposition 5 is that without the option to coordinate, the innovator might strategically decide to remain small to stay "under the radar screen" and avoid responses by the incumbent. To illustrate this, note that if the new technology's attractiveness is low (i.e., p_G is low), so that the new technology is abandoned in both cases, the cost of motivating the R&D team is the same. However, being small allows the innovator to steal market share from the incumbent technology, which could be more profitable than coordination. What is important, is that this might be preferable also for the incumbent. The latter can influence the innovator's size decision by choosing private ownership or not buying a stake in the innovator, since this precludes coordination opportunities even when the innovator is large.

4.3 Extension: Private Ownership and Voluntary Reporting

We have assumed so far that a firm can make its signal $s \in \{c, nc\}$ public under public, but not under private ownership. However, one could argue that also 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 published. No such regulation applies to private firms, and when reporting requirements exist, the required quality is much coarser than that for public firms. In what follows we analyze the consequences for coordination when both firms operate the same technology. Without loss for the qualitative results, we assume that one of the firms is public, while the other private. We continue to assume that a firm's signal is public information under public ownership. However, we now also allow the private firm to reports its cash flows, but (facing laxer regulation), the private firm can choose to communicate its report with noise $\eta \in [0, \overline{\eta}]$, such that its true signal s is interpreted as $s' \neq s$ with probability η. The upper bound $\overline{\eta} < 1$ captures the private firm's discretion of communicating less precise information. In what follows, we maintain Assumption 2.

Consider the same candidate equilibrium as in Section 3.1 according to which each firm coordinates in period one, and coordinates 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 proposed equilibrium strategies of coordinating in the first period, and suppose that at the end of that period the public firm infers c (which becomes then common knowledge). If the private firm infers signal nc from its cash flows, we know from Section 3.1 that it has incentives to neglect this negative signal and coordinate again. Consider, therefore, the consequences of adding noise η to the private firm's report: With probability η, the public firm infers c and coordinates, and with with probability $1-\eta$, it infers nc and does not coordinate. Hence, the private firm's payoff from coordinating in period two is $\eta x_C + (1-\eta)(x_C - m)$, while from not coordinating $\eta b x_{NC} + (1-\eta) x_{NC}$. Two insights follow immediately. First, in both cases the private firm's period-two payoffs increase from adding noise to its report. Thus, without the ability to commit not to add noise, the private firm will choose the ex post maximum level $\overline{\eta}$. Second, comparing the two payoffs, coordinating in period two is ex post beneficial if

$$\eta > \eta^* \equiv \frac{x_{NC} - (x_C - m)}{x_C - b x_{NC} - (x_{NC} - (x_C - m))} \tag{3}$$

Hence if $\overline{\eta} > \eta^*$, the private firm will choose to coordinate also in the second period following But then, going back to period one, we have again the problem that, expecting this behavior, the public firm will not start coordinating. Thus, coordination cannot be sustained.

Even if (3) is not satisfied ($\overline{\eta} < \eta^*$), the private firm's ex post incentive to add the maximum level of noise to its report reduces the public firm's payoffs from following the proposed equilibrium strategy in period one relative to one in which it does not coordinate in both periods. Thus, overall, we continue to obtain that private ownership reduces the likelihood of coordination even when voluntary reporting is possible.

Corollary 4 *With voluntary disclosure in the case of private ownership, though, ex ante, the private firm would like to commit not to add noise to its report, ex post, it adds the maximum amount of noise. This lack of commitment problem reduces the opportunities for coordination.*

5 Empirical Implications

First, we discuss the implications of our model when firms coordinate on existing technologies. Subsequently, we discuss the model's predictions concerning the choice between public, private, and shared ownership and its effect on innovation.

The question why private firms choose to go public is long-standing in the finance literature. Key reasons that have been given 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 to this discussion, which is surprisingly neglected in prior work: facilitating coordination.

Implication 1 *Profits of public firm are higher than they should be under head-to-head competition.*

By endogenizing the choice of public ownership, our paper shows that firms choose public ownership if they fear that head-to-head competition will erode their future profits. Thus, despite evidence that profits decline after firms go public (Pastor et al., 2009), we argue that these profits are higher than would have been the case in a competitive market. Indeed, high profit margins in the tech, biotech and pharma industries, as well as in traditional, cartel-prone industries, such as rail and air travel are hard to square with a competitive market and have recently gained considerable media attention.[11]

[11] See Larry Summer's article cited in footnote 1.

Recent advances in information technology have made it possible that private firms communicate valuable information about themselves to outsiders even without public ownership. As highlighted by Corollary 4, this could allow even private firms to achieve coordination. With the advance of new technologies, such as the blockchain, that further improve the verifiability of information, we expect such development to become even stronger in the future. This could have a negative impact on competition.

Implication 2 *Advances in information technology that ease the (credible) dissemination of information would help coordination even under private ownership and would allow also private firms to retain high margins without going public.*

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

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

Coordination can be achieved also through non-controlling equity stakes (Proposition 3). However, such coordination is not a substitute for public ownership, as it has additional negative effects on innovation. Furthermore, it is typically infeasible for small firms to buy stakes in much larger firms (Allen and Phillips, 2000). In such cases, coordination will only be achieved if the large firm is public. Thus, strategically buying non-controlling stakes in small innovators is more likely to emerge when public equity markets are more developed. This is consistent with the evidence that Corporate Venture Capital (CVC), which specializes in taking strategic minority stakes in innovators, is better developed in such markets, but is not associated with stronger competition in such markets (Dushnitsky, 2006).

Implication 4 *(i) Well-developed public equity markets increase the likelihood of coordination, as coordination through non-controlling equity stakes is not a perfect substitute for* *public ownership. (ii) Corporate venture capital will go hand-in-hand with more-developed equity markets, but it will contribute to softening competition in such markets.*

In a recent paper Azar et al. (2016) find that financial investors, such as BlackRock, who own stakes in competing firms could contribute to softer competition among these firms. The paper's motivation is based on the argument that if the same investor owns 50% of two firms, the management of either firm will take both firms' profits equally into account in their optimization decisions. Implication 4 cautions against drawing stark regulatory implications based on such findings, as public ownership alone could also act as a coordination mechanism.

Our second set of implications investigates how coordination and the choice between public and private ownership interacts with innovation incentives. Our first key insight is that private ownership could help overcome the time-inconsistency problem that a firm would like to commit to pursuing the development of a new technology. Specifically, it avoids the temptation of abandoning development in case of early difficulties in favor of coordinating on a profitable existing technology (Proposition 1). There is more tolerance for failure also if the incumbent buys the innovator, as then the incumbent operates the existing technology anyhow, so it faces no temptation to abandon the development of the new one.

Implication 5 *If an innovator seeks to develop a new technology (and faces no competition on this from the incumbent), private ownership makes it more tolerant for failure, in the sense that it is less likely to abandon the new technology in the face of early difficulties.*

However, a higher tolerance for failure is not necessarily in the best interest of the innovator. First, if the new technology is not expected to be very profitable, the innovator might prefer to have the option to coordinate and choose public ownership (Corollary 2). This hurts innovation, but benefits the firm at the expense of consumers. Second, private ownership might even be bad for innovation if the innovator faces competition on innovation from the incumbent. In this case, the opportunity to coordinate not to compete away each others' profits in case both firms succeed in the new technology, spurs innovation incentives.

Implication 6 *Public ownership dominates private ownership (i) if the expected profitability is low, so that the value of the option to fall back on high-margin existing technology is high; or (ii) if the expected profitability is high, so that the innovator could benefit from* *coordinating with the incumbents on the existing technology. For intermediate values, private ownership is more beneficial, as it helps to deal with the time inconsistency problem of not being able to commit not to prematurely abandon the new technology's development.*

Implication 6 could help understand why private firms are not always champions in innovation, despite the prediction of prior theory (Ferreira et al., 2012) and the evidence of some empirical settings (Bernstein, 2015). Indeed, many public firms, such as Apple, Google, and Tesla, are paramount examples of innovation. We predict that private ownership will be unambiguously better for innovation only in the case of new technologies that do not appear sufficiently interesting to incumbents to warrant investments in technologies that cannibalize their existing business. However, as we show in Proposition 4:

Implication 7 *If both an innovator and an incumbent seek to develop new technologies, public ownership could sharpen the incentives to innovate.*

Finally, based on Proposition 5, we predict:

Implication 8 *(i) Large private firms could be more tolerant to early discouraging news compared to small private firms, as for large firms adopting the incumbent's technology is more likely to trigger a price war. (ii) Innovators might have incentives to remain small, but this is bad for their innovation incentives.*

6 Conclusion

We develop a model in which firms choose public over private ownership when they want to tacitly coordinate on a technology to retain high margins. Though neither public nor private ownership confers direct insights into a firm's actions, under public ownership firms' cash flows are public information, and signals inferred from these cash flows are informative and common knowledge. This makes punishments for deviations a credible threat and facilitates tacit coordination. Thus, firms will choose public ownership when their technology is becoming commoditized and they seek to retain high profits.

Not all firm benefit from public ownership, however. Being able to coordinate on an existing technology is a double-edge sword if an innovator seeks to develop a new technology, as then the temptation to abandon its development in case of early difficulties is high. In such cases, firms could be faced with a time inconsistency problem, and private ownership might be better. It helps to commit to the long-term pursuit of innovation and improves incentives.

Taking these results as a starting point, we derive a number of novel implications about a firm's choice between public and private ownership. We find that there is a U-shaped relationship between the new technology's expected profitability and the attractiveness of public ownership. If the profitability is low, the option to coordinate on the incumbent's technology is very valuable, and public ownership dominates. However, if the new technology's expected profitability is higher, being able to commit not to abandon it in the face of early difficulties becomes more valuable. In this case, private ownership dominates. However, if the new technology is sufficiently profitable that it is never abandoned, public ownership dominates again. This is particularly true if the incumbent could also attempt to develop the new technology, as then being able to coordinate in case both firms are successful becomes important.

Also the innovator's size matters, as large incumbents would not bother to respond to small rivals. Hence, small innovators will tend to abandon the development of new technologies faster even under private ownership, as they can free ride on the high margins of the incumbent technology. Moreover, they might have incentives to remain small to avoid the need to coordinate. This has a negative impact on innovation.

An alternative to public ownership as a coordination device is buying non-controlling or controlling equity stakes in competitors. A non-controlling stake in an innovator could give an incumbent the possibility to observe the innovator's cash flows. Hence, coordination might be achieved without the innovator being public. However, equity stakes and public ownership are not perfect substitutes for achieving coordination, as buying equity stakes reduces the incumbent firm's innovation incentives by allowing it to benefit from the innovator's success. With a controlling stake or a takeover, coordination is automatic, which leads to a partial specialization. The incumbent's innovation incentives decrease further, while those of the innovator increase compared to when the two firms operate separately. The reason is that, absent the opportunity cost of missed coordination, the incumbent is more likely to continue the development of the new technology even in light of early discouraging signals. This is reinforced by the fact that, absent competition, the returns to innovation increase. We expect that firms will shift to such coordination mechanisms when the cost of public ownership increase. This could help explain why the recent decline in public ownership has been accompanied with an increase in takeover activity.

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Appendix

Proof of Proposition 2. Define y_C to be the innovator's two-period payoff when both firms use the incumbent technology and coordinate, and let y_{NC} be expected payoff when they do not coordinate. There is a trade-off between public and private ownership when the continuation decision differs for $\theta = \theta_B$. Suppose, therefore, that $\theta_G x_{FM} > y_C > \theta_B x_{FM} > y_{NC}$ (note that there can be no single-period coordination 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 (coordination) and private (non-coordination) ownership. Observe that, since θ is not contractible, whenever the new technology is abandoned, the R&D team must receive the same wage, independent of θ.

Public ownership and coordination at $t = 0.5$. The innovator takes the ex post efficient decision to abandon the new technology and coordinate with the incumbent after observing θ_B if $y_C - w_A > \theta_B (x_{FM} - w)$. Since $\theta_B x_{FM} < y_C$, a sufficient condition is that $\theta_B w \geq w_A$. Suppose for now that this is satisfied (below we show that it is, as $w_A = 0$). The innovator maximizes[12]

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

subject to the R&D team's incentive constraint

$$-(\tau_G + \tau_B) w_A + \tau_B w_A + \tau_G \theta_G w \geq c. \tag{4}$$

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

$$(1 - p_B - \tau_B - p_G - \tau_G) y_C + (p_B + \tau_B) y_C + (p_G + \tau_G)\theta_G x_{FM} - \frac{(p_G + \tau_G)}{\tau_G} c. \tag{5}$$

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

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

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

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

$$\begin{aligned}&(1 - p_B - \tau_B - p_G - \tau_G)\, y_{NC} + (p_B + \tau_B)\,\theta_B x_{FM} \\ &+ (p_G + \tau_G)\,\theta_G x_{FM} - \frac{(p_G + \tau_G)\,\theta_G + (p_B + \tau_B)\,\theta_B}{\tau_G\theta_G + \tau_B\theta_B} c.\end{aligned} \tag{7}$$

Recall that continuation after observing θ_B requires

$$\theta_B x_{FM} - y_{NC} > \theta_B w = \frac{\theta_B c}{\tau_G\theta_G + \tau_B\theta_B} \tag{8}$$

(i.e., y_{NC} is sufficiently low). Suppose that the inequality in (8) is not satisfied. Then the innovator does not have the right incentives at $t = 0.5$ to take the efficient continuation decision. This creates scope for renegotiations, in which the R&D team extracts γ of the additionally generated surplus. Denoting the R&D team's payoff in that case with w_R, we have

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

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

$$-(\tau_G + \tau_B)\, w_A + \tau_B\,(w_A + \gamma\,(\theta_B x_{FM} - y_{NC})) + \tau_G\theta_G w \geq c. \tag{9}$$

It is optimal to set $w_A = 0$ and $w = \frac{c - \tau_B\gamma(\theta_B x_{FM} - y_{NC})}{\tau_G\theta_G}$.[13] The innovator's expected payoff is

$$\begin{aligned}&(1 - p_B - \tau_B - p_G - \tau_G)\, y_{NC} + (p_B + \tau_B)\,(\theta_B x_{FM} - \gamma\,(\theta_B x_{FM} - y_{NC})) \\ &+ (p_G + \tau_G)\left(\theta_G x_{FM} - \theta_G \frac{c - \tau_B\gamma\,(\theta_B x_{FM} - y_{NC})}{\tau_G\theta_G}\right) \\ =\ &(1 - p_B - \tau_B - p_G - \tau_G)\, y_{NC} + (p_B + \tau_B)\,\theta_B x_{FM} \\ &+ (p_G + \tau_G)\,\theta_G x_{FM} + \gamma\,(\theta_B x_{FM} - y_{NC})\left(\frac{\tau_B}{\tau_G} p_G - p_B\right) - \frac{(p_G + \tau_G)}{\tau_G} c.\end{aligned} \tag{10}$$

Subtracting now the innovator's payoff under non-coordination from that under coor-

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

$$\begin{aligned}\theta_B x_{FM} - y_{NC} - \theta_B \frac{c - \gamma\tau_B\,(\theta_B x_{FM} - y_{NC})}{\tau\theta_G} &= \frac{1}{\theta_G}\left((\theta_B x - y_{NC}) - \frac{\theta_B c}{\tau_G\theta_G + \theta_B\tau_B\gamma}\right) \\ &\leq \frac{1}{\theta_G}\left((\theta_B x - y_{NC}) - \frac{\theta_B c}{\tau_G\theta_G + \theta_B\tau_B}\right) < 0.\end{aligned}$$

dination, we obtain

$$\left(1-p_B-\tau_B-p_G-\tau_G\right)\left(y_C-y_{NC}\right)+\left(p_B+\tau_B\right)\left(y_C-\theta_B x_{FM}\right)-c\theta_B\frac{\frac{\tau_B}{\tau_G}p_G-p_B}{\tau_G\theta_G+\tau_B\theta_B} \tag{11}$$

if there are no renegotiations under non-coordination, and

$$\left(1-p_B-\tau_B-p_G-\tau_G\right)\left(y_C-y_{NC}\right)+\left(p_B+\tau_B\right)\left(y_C-\theta_B x_{FM}\right)-\gamma\left(\theta_B x_{FM}-y_{NC}\right)\left(\frac{\tau_B}{\tau_G}p_G-p_B\right) \tag{12}$$

if there are renegotiations. Hence, as long as $\frac{\tau_B}{\tau_G}p_G > p_B$, the R&D team's compensation is lower under non-coordination than under coordination, regardless of whether or not (8) is satisfied. Furthermore, both (11) and (12) decrease in p_B, p_G, and $\frac{\tau_B}{\tau_G}$. In particular, there is a threshold $\widehat{p}_G$, such that non-coordination is better for the innovator for all $p_G > \widehat{p}_G$. This threshold decreases (i.e., non-coordination is more attractive) in $\frac{\tau_B}{\tau_G}$, p_B, and x_{FM}.

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

Proof of Proposition 3. Observe, first, that the innovator's gross expected payoff is x_{FM} if only it successfully develops the new technology, 0 if it is unsuccessful in developing the new technology, and $y_O = 2x_O$, if both firms successfully develop the new technology, where $O \in \{C, NC\}$ stands for whether or not the two firms coordinate. At $t = 0.5$, it is optimal to abandon the new technology if $(1-\rho)\,\theta x_{FM}+\rho\theta y_O < (1-\rho)\,y_O$ or equivalently if

$$\theta x_{FM}+\frac{\rho}{1-\rho}\theta y_O < y_O. \tag{13}$$

Hence, the abandonment threshold is higher than without competition. In particular, since $\frac{\rho}{1-\rho}$ increases in ρ, abandonment is never optimal if ρ is sufficiently high. (In this case, private ownership would have no advantage, and public ownership would be always preferable.)

In what follows, we consider the case in which for θ_B, condition (13) holds for y_C, but not for y_{NC}, such that abandonment in state θ_B is optimal under public, but not under private ownership (in all other cases, public ownership dominates). We denote with w_{comp} the R&D team's wage in case both firms successfully develop the new technology.

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

$$-\left(\tau_B+\tau_G\right)w_A+\tau_B w_A+\tau_G\left(\left(1-\rho\right)\theta_G w+\rho\theta_G w_{comp}\right)\geq c$$

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

$$\begin{aligned}&\left(1-p_B-\tau_B-p_G-\tau_G\right)\left(1-\rho\right)y_C+\left(p_B+\tau_B\right)\left(1-\rho\right)y_C\\&+\left(p_G+\tau_G\right)\left(\left(1-\rho\right)\theta_G x_{FM}+\rho\theta_G y_{NC}\right)-\frac{\left(p_G+\tau_G\right)}{\tau_G}c.\end{aligned}$$

Private ownership and non-coordination 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

$$-\left(\tau_G+\tau_B\right)\left(1-\rho\right)w_A+\left(\tau_G\theta_G+\tau_B\theta_B\right)\left(\left(1-\rho\right)w+\rho w_{comp}\right)\geq c$$

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

$$\begin{aligned}&\left(1-p_B-\tau_B-p_G-\tau_G\right)\left(1-\rho\right)y_C+\left(p_B+\tau_B\right)\left(\left(1-\rho\right)\theta_B x_{FM}+\rho\theta_B y_{NC}\right)\\&+\left(p_G+\tau_G\right)\left(\left(1-\rho\right)\theta_G x_{FM}+\rho\theta_G y_{NC}\right)-\frac{\left(\left(p_G+\tau_G\right)\theta_G+\left(p_B+\tau_B\right)\theta_B\right)}{\tau_G\theta_G+\tau_B\theta_B}c.\end{aligned}$$

Recall that continuation after observing θ_B requires that

$$\left(1-\rho\right)\theta_B x_{FM}+\rho\theta_B y_{NC}-\left(1-\rho\right)y_{NC}>\frac{\theta_B c}{\tau_G\theta_G+\tau_B\theta_B}. \tag{14}$$

Suppose that the inequality in (14) 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 $w_R := w_A+\gamma\left(\left(1-\rho\right)\theta_B x_{FM}+\rho\theta_B y_{NC}-\left(1-\rho\right)y_{NC}\right)$. Hence, at the contracting stage $t = 0$, the R&D team's incentive constraint is

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

Hence, it is optimal to set $w_A = 0$ and $\left(1-\rho\right)w+\rho w_{comp} = \frac{c-\tau_B w_R}{\tau_G\theta_G}$.[14] The innovator's

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

expected payoff is

$$\begin{aligned}&\left(1-p_B-\tau_B-p_G-\tau_G\right)(1-\rho)\, y_C+\left(p_B+\tau_B\right)\left((1-\rho)\,\theta_B x_{FM}+\rho\theta_B y_{NC}\right)\\&+\left(p_G+\tau_G\right)\left((1-\rho)\,\theta_G x_{FM}+\rho\theta_G y_{NC}\right)+\left(\frac{\tau_B}{\tau_G}p_G-p_B\right)w_R-\frac{\left(p_G+\tau_G\right)}{\tau_G\theta_G}c\end{aligned}$$

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

$$\begin{aligned}&\left(1-p_B-\tau_B-p_G-\tau_G\right)(1-\rho)\left(y_C-y_{NC}\right)\\&+\left(p_B+\tau_B\right)\left((1-\rho)\, y_C-(1-\rho)\,\theta_B x_{FM}-\rho\theta_B y_{NC}\right)\\&+\left(p_G+\tau_G\right)\rho\theta_G\left(y_C-y_{NC}\right)-c\theta_B\frac{\frac{\tau_B}{\tau_G}p_G-p_B}{\tau_G\theta_G+\tau_B\theta_B}\end{aligned}\tag{15}$$

if there are no renegotiations under non-coordination, and

$$\begin{aligned}&\left(1-p_B-\tau_B-p_G-\tau_G\right)(1-\rho)\left(y_C-y_{NC}\right)\\&+\left(p_B+\tau_B\right)\left((1-\rho)\, y_C-(1-\rho)\,\theta_B x_{FM}-\rho\theta_B y_{NC}\right)\\&+\left(p_G+\tau_G\right)\rho\theta_G\left(y_C-y_{NC}\right)-\left(\frac{\tau_B}{\tau_G}p_G-p_B\right)w_R\end{aligned}\tag{16}$$

if there are renegotiations. The result follows from (15) and (16). **Q.E.D.**

Proof of Corollary 2. If p_G is very low, neither firm starts the new technology's development and public ownership dominates. If p_G is very high, both firms start the new technology's development and never abandon it (see (13)). Finally, to deal with all remaining cases, suppose that p_G is high enough that the innovator starts developing the new technology, but that this technology is abandoned if the innovator observes θ_B under private, but not under public ownership. The difference in payoffs between public and private ownership is a convex function of p_G. To see this, use that $\frac{\partial\rho}{\partial p_G}=\theta_G$ and take the second derivative of (15) with respect to p_G to obtain

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

The second derivative of (16) with respect to p_G is the same. Thus, the attractiveness of public ownership is a convex function of p_G. Together, all of this implies a U-shaped relationship between p_G and the attractiveness of public ownership. **Q.E.D.**

Proof of Proposition 4. (i) Let ρ^{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

$$(1-\beta) V^{Inc} + \beta V^{Inov,comp} - k \geq (1-\beta)\left(1-\rho^{Innov}\right) y_C + \beta V^{Innov,no\ comp} \tag{17}$$

Consider as a benchmark the case in which $\beta = 0$ and the incumbent is just indifferent. Since $V^{Innov,no\ comp} > V^{Inov,comp}$, this implies that we must have $V^{Inc} > \left(1-\rho^{Innov}\right) y_C$. But differentiating both sides of (17) with respect to β, this implies that increasing β, makes condition (17) more difficult to satisfy.

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

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

As shown in Proposition 2, this leads to a lower compensation cost than if the new technology is abandoned in case of θ_B. Moreover, absent competition, the incumbent's profit in case of success are higher, increasing the likelihood that the new technology's development is initiated. **Q.E.D.**

Proof of Proposition 5. (i) Suppose that both firms adopt the same technology in periods one and two and that Assumption 2 is not satisfied for the incumbent. Since $2x_C - bx_{NC} > K$ and $x_C - m > x_{NC}$, playing C in both periods is a dominant strategy for the incumbent regardless of the action taken by the innovator.

(ii) If the innovator is large, it is one of four cases applies: It is public and innovates alone; It is private and innovates alone; it is private and competes with the incumbent on innovation; it is public and competes with the incumbent on innovation.

In the first region, the innovator abandons the new technology following signal θ_B regardless of whether it is large or small. Hence, the cost of motivating the R&D team is the same, and remaining small is preferable (cf. 5) if

$$\begin{aligned} & \left(1-p_B-\tau_B-p_G-\tau_G\right) 2bx_{NC}+\left(p_B+\tau_B\right) 2bx_{NC}+\left(p_G+\tau_G\right) \theta_G x_{FM}-\frac{\left(p_G+\tau_G\right)}{\tau_G} c \\ > \quad & \left(1-p_B-\tau_B-p_G-\tau_G\right) 2\varphi x_C+\left(p_B+\tau_B\right) 2\varphi x_C+\left(p_G+\tau_G\right) \theta_G \varphi x_{FM}-\frac{\left(p_G+\tau_G\right)}{\tau_G} c, \end{aligned} \tag{18}$$

that is if φ is sufficiently small relative to b. We omit the argument for the remaining regions, as it is analogous.[15]

Finally, note that if m is sufficiently small, the incumbent might prefer that the innovator remains small despite stealing market share. The incumbent can influence this decision by choosing private ownership or not buying an equity stake in the innovator. To see this, observe that in these cases, we have to replace x_C with x_{NC} in the right-hand-side of inequality (18), which makes remaining small more attractive. **Q.E.D.**

[15] For example, in the second region, the innovator's compensation cost is higher when it is small, as it continues developing the new technology if large (and private), but not if it is small. Remaining small is, thus, profitable if (see (11)):

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

or respecitvely

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

giving again a critical value for φ.