Monopsony Power and Upstream Innovation*

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August 23, 2022

Abstract

How does a monopsonist incentivize its supplier to innovate? By decreasing the short-run profit of the supplier, the monopsonist can increase the supplier's incentive to invest in R&D by lessening the supplier's Arrow's replacement effect. The monopsonist engages in this practice despite a distortion in its trade volume with the supplier that causes inefficiency. We discuss implications for the boundaries of the firm.

Keywords: Monopsony, innovation, vertical relationships, boundaries of the firm

*The ⓡ symbol indicates that the authors are in random order, as described by Ray and Robson (2018). The authors thank Matthew Mitchell (Editor), one anonymous referee, Nancy Gallini, Ekaterina Khmelnitskaya, Gerard Llobet and workshop participants at UBC and the 56th Annual Canadian Economics Association Meetings for helpful comments and suggestions. All errors are our own. Guillermo Marshall and Álvaro Parra are supported in part by funding from the Social Sciences and Humanities Research Council of Canada.

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1 Introduction

Firms in innovative industries rely on global supply chains to create new products. For example, Boeing reports having contracts with more than 20,000 diverse suppliers and partners.[1] A natural question to ask is then: How does a firm incentivize R&D that takes place outside of its boundaries?

News reports suggest that companies like Tesla, Apple, Boeing, and other firms in innovative industries "squeeze" their suppliers when needing to improve their products. For example, Apple suppliers reported that Apple cut component prices and order volumes in 2016, promising that terms would improve after new-device launches.[2] Ford cut component prices by 3.5 percent in 2003 and requested suppliers to develop design cost savings of 20%.[3] "Squeezing"—which we define as cuts in input prices and order volumes—happens even though suppliers play a crucial role in developing innovations for the supply chain.

Is the "squeezing" consistent with downstream firms seeking to incentivize upstream innovation? A firm's incentive to innovate crucially depends on Arrow's replacement effect (Arrow, 1962), which measures the difference between the profit flow of the new product (i.e., the innovation) and that of the existing product. When this profit difference is small, the incentives to invest are small, as the firm has little to gain by replacing its existing product. The opposite is true when the profit difference is large. A strategic downstream firm with monoposony power (*monopsonist*, henceforth) can therefore squeeze its supplier to boost its supplier's R&D incentives, as squeezing decreases the supplier's profit, lessening the supplier's Arrow's replacement effect. From the perspective of the monopsonist, squeezing is productive in incentivizing upstream innovation, but we show that it is costly in terms of efficiency, as it forces a distortion in the trade volume along the supply chain.

We formally show the existence of the squeezing incentive in the context of a model of a vertical supply chain with upstream innovation. The model features a downstream monopsonist procuring inputs from a supplier. The supplier has the ability to invest in R&D to develop an innovation that enhances the value of the supply chain. In the baseline model, we assume that the monopsonist uses a linear contract in its dealings with the supplier and must use the linear contract to incentivize production and R&D. We make this choice inspired by our motivating examples and growing evidence on the use of linear contracts along vertical supply chains.[4] We show that our results extend to the case of non-linear contracts in Online

[1] https://www.boeing.com/global/

[2] https://www.wsj.com/articles/apple-squeezes-parts-suppliers-to-protect-margins-1472713073

[3] https://www.wsj.com/articles/SB10691146306292100

[4] See, for example, Luco and Marshall (2020); Bajo-Buenestado and Borrella-Mas (2020); Marshall (2020).

Appendix B.

In the model, in every period of the game, the monopsonist sets an input price, and the supplier responds by choosing how many units of the input to supply and how much to invest in R&D (i.e., a Poisson arrival rate that governs the speed at which the innovation is invented). The supplier faces convex costs of production, which imply that its supply curve is increasing in the input price set by the monopsonist. The monopsonist faces a revenue function that is increasing in the input quantity (i.e., more inputs enable more downstream production and revenue), which implies that squeezing is costly for the monopsonist, as it implies a distortion in input volumes (and thus revenue).

How does the monopsonist set its price? The monopsonist chooses its input price by setting marginal revenue equal to marginal cost, where marginal cost has three components. The first two relate to upstream production. When the supply curve is increasing in input price, demanding an extra unit of the input requires increasing the input price (first effect). Since the contract is linear, this input price increase applies to all inframarginal units as well (second effect). The third effect is that demanding an extra unit of the input (or increasing the input price), increases the profit flow of the supplier, magnifying its Arrow's replacement effect and thus inducing less upstream R&D. Purchasing the extra unit of the input is thus costly for the monopsonist because the monopsonist wishes to obtain the innovation as soon as possible, and less R&D will delay its arrival. This third effect creates the incentive to squeeze the supplier so long the supplier is working on the R&D project and is the novel mechanism that we isolate in this article.

The squeezing effect magnifies the inefficiency caused by the downstream firm's monopsony power: to sustain the squeezing, trade between the monopsonist and the supplier decreases, which forces the monopsonist to sell fewer units of the downstream product and earn less revenue. This efficiency loss, caused by the squeezing effect, motivates us to ask: When will the squeezing effect cause firms to reshape their boundaries by choosing to vertically integrate? Starting from situations where the firms would not want to change their boundaries in the absence of squeezing, we find that firms only reshape their boundaries when the magnitude of the innovation is sufficiently large, which is when the squeezing effect is exacerbated. This result can explain why firms in innovative industries are squeezing their suppliers and why we do not observe them revising their boundaries to avoid the efficiency loss of squeezing.

Our work relates to several strands of the literature. It first relates to work investigating the relationship between buyer power and market outcomes (e.g., von Ungern-Sternberg 1996; Dobson and Waterson 1997). Within this strand of the literature, our work is closest to articles studying how buyer power impacts investment and R&D incentives of suppliers

(Vieira-Montez, 2007; Inderst and Wey, 2011; Chen, 2019). Inderst and Wey (2011) and Chen (2019) present similar findings to ours—i.e., buyer power can enhance upstream innovation—in a setting where suppliers and downstream firms bargain efficiently. In both articles, the increase in supplier R&D incentives is driven by how innovation can decrease buyers' outside option, improving the supplier's equilibrium payoff. Our article focuses on a different mechanism: the buyer can use its monopsony power to manipulate the R&D incentives of the supplier. Unlike the work of Inderst and Wey (2011) and Chen (2019), the greater equilibrium R&D investments are induced by the buyer (via lower input prices) rather than being a strategic response by the supplier to impact bargaining outcomes.

We also contribute to the literature studying how firms seek to affect the non-price behavior of rival firms by strategically manipulating product-market profits. Gallini (1984) shows that incumbents may have an incentive to licence their innovations to entrants to boost entrants' profits and decrease their incentives to invest in R&D. Relatedly, Marshall and Parra (2021) show that firms have incentive to increase their prices to soften price competition and decrease the R&D incentives of rival firms. Byford and Gans (2014, 2019) show that in a natural oligopoly, it can be profitable for a firm to raise its price when this avoids the exit of a weak rival, where the goal is to prevent the weak rival from being replaced by a stronger competitor.

Our work also relates to the literature on the theory of the firm (Coase, 1937), and in particular, to the work on the impact of ownership (or vertical structure) on investments in relationship-specific assets (Williamson, 1975, 1979; Joskow, 1985; Grossman and Hart, 1986; Joskow, 1988). We also contribute to the literature on innovation incentives (Schumpeter, 1942; Arrow, 1962). Our model of R&D is in part based on work by Loury (1979), Lee and Wilde (1980), and Reinganum (1982) and our results speak to the relationship between vertical structure and innovation (Armour and Teece, 1980; Acemoglu *et al.*, 2003; Brocas, 2003; Chen and Sappington, 2010; Liu, 2016; Yang, 2020).

Finally, this article contributes to a growing literature on how market power affects innovation outcomes. This relation has been studied in the context of (killer) acquisitions (Cunningham *et al.*, 2021; Letina *et al.*, 2021), horizontal mergers (Letina, 2016; Federico *et al.*, 2017, 2018; Denicolò and Polo, 2018; Hollenbeck, 2020; Motta and Tarantino, 2021), and different market structures (Marshall and Parra, 2019). We contribute to this literature by studying how vertical market power and changes in the vertical boundaries of the firm affect innovation outcomes.

2 A Model of Monopsony and Upstream Innovation

Set up Consider a monopsonist acquiring inputs from a supplier using a linear contract. The monopsonist chooses the input price w. The supplier takes the price w as given and decides how much input q to sell. The supplier's cost of producing q units is given by the cost function $c(q)$, which is convex and twice differentiable, satisfying $c'(0) = 0$, $c'(q) > 0$ and $c''(q) > 0$ for all $q > 0$. The supplier has an R&D investment opportunity, leading to an innovation that arrives at a stochastic time. Let $i \in \{0, 1\}$ be an index denoting whether an innovation has been achieved. Except where noted, we assume that state i is verifiable by third parties, making innovation-contingent contracts enforceable in court.

The monopsonist derives revenue $R_i(q)$ when purchasing q units of the input under technology i. The revenue function is increasing, weakly concave and twice differentiable, satisfying $R_i(0) = 0$, $R_i'(q) > 0$ and $R_i''(q) \leq 0$ for all $q > 0$ and i. We assume that, for all q, $R_1'(q) > R_0'(q)$, which implies that $R_1(q) > R_0(q)$ for all $q > 0$. That is, the innovation increases the revenue achieved with a given level of inputs. This formulation accommodates the cases of cost-saving and quality innovations.

Time is continuous and payoffs are discounted at a rate $r > 0$. Before the innovation has been invented ($i = 0$), the supplier makes simultaneous production and R&D investment choices at every instant of time given the state variable w, which is the input price set by the monopsonist. The supplier invests in R&D by choosing a Poisson innovation rate x at a convex R&D cost of $\kappa(x)$, which satisfies $\kappa(0) = 0$, $\kappa'(x) > 0$ and $\kappa''(x) > 0$ for all $x > 0$. The convex costs (of R&D and production) and concave revenue assumptions guarantee that second-order conditions hold throughout the article.

Equilibrium without R&D At every instant in time, given the input price w set by the monopsonist, the supplier chooses the quantity q that maximizes its profit. We assume that no R&D takes place, but we solve for the equilibrium of the game in the two technology states (i.e., $i \in \{0, 1\}$), as we will later refer back to these results.

In the case without R&D, the dynamic problem reduces to a static monopsony pricing problem, as production decisions are time independent. That is, the supplier solves

$$\pi_s(w) = \max_q \{w \cdot q - c(q)\}. \tag{1}$$

The optimal input quantity chosen by the supplier is given by the solution to the equation

$$w = c'(q). \tag{2}$$

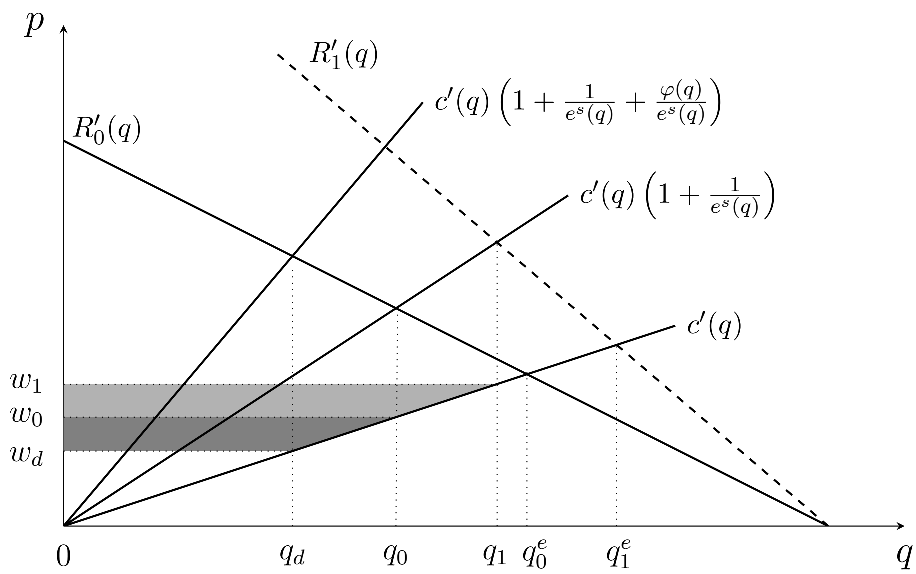

Figure 1: Innovation incentives. Depiction of the marginal revenue curves (before and after the innovation) and the marginal cost curves (of production, for the static monopsonist, and the dynamic monopsonist.) The shaded area illustrates the suppliers' incentives to innovate, i.e., the incremental profit $\pi_s(w_1)-\pi_s(w_d)$ associated with the innovation. The dark-shaded area represents the extra innovation incentives induced by the monopsonist squeezing the supplier.

Using the envelope theorem, we can verify that the supplier's profit is increasing in w: $\pi_s'(w) = q(w)$. Equation (2) also gives an implicit expression for the supplier's supply curve, $q(w)$, which is increasing in w: $q'(w) = 1/c''(q(w)) > 0$.

Knowing the supplier's response to w, $q(w)$, the monopsonist chooses the optimal linear contract w_i that solves

$$\pi_i^m \equiv \max_{w_i}\{R_i(q(w_i)) - w_i \cdot q(w_i)\}, \tag{3}$$

where i is the technology state. The optimal pricing condition is given by input price that equates the monopsonist's marginal revenue to its marginal costs, that is

$$R_i'(q(w_i)) = w_i\left(1+\frac{1}{e^s(w_i)}\right). \tag{4}$$

The monopsonist's marginal cost consists of the average input price w_i plus the extra cost that the monopsonist must pay for all inframarginal units when demanding an additional unit—recall that the supply curve is upward-sloping. The latter term is given by $w_i/e^s(w_i)$, which depends on the elasticity of the supply curve at w_i (i.e., $e^s(w) \equiv \partial q(w)/\partial w \cdot w/q(w)$). Figure 1 plots the left- and right-hand sides of equation (4), making use of the supplier's optimality condition $w = c'(q)$ in equation (2). It also shows the optimal input price w_i and quantity q_i.

Efficient benchmark The efficient outcome is given by the output that equates marginal revenue to marginal cost of production, i.e., $R_i'(q_i^e) = c'(q_i^e)$. Later in the article, this will correspond to the output of a vertically integrated firm. Figure 1 illustrates the efficient output under technology i, q_i^e.

Upstream Innovation We now analyze the supplier's incentives to invest in the R&D project and how the monopsonist can manipulate these incentives with the linear contract that governs the vertical supply chain.

In the post-innovation subgame, we assume that the monopsonist chooses the input price according to the static solution in equation (4) (we discuss this assumption at the end of this section). Let $V_1^m = \pi_1^m/r$ and $V_1^s = \pi_s(w_1)/r$ be the monopsonist and supplier post-innovation values (see equations 1 and 3), respectively.[5]

Before the arrival of the innovation, at every instant in time, the supplier maximizes its value by solving

$$rV_0^s(w) = \max_x \{\pi_s(w) - \kappa(x) + x(V_1^s - V_0^s(w))\}, \tag{5}$$

where w is the input price. Here we leverage that the optimal production and R&D decisions are separable from the supplier's perspective and $\pi_s(w)$ is the supplier profit function. The supplier's value given input price w, $V_0^s(w)$, is the discounted sum of its profit flow $\pi_s(w)$, net of R&D costs, plus the increase in value from an innovation $V_1^s - V_0^s(w)$, which is obtained at rate x.

The solution to this problem, $x^*(w)$, solves the equation

$$\kappa'(x) = V_1^s - V_0^s(w). \tag{6}$$

The supplier invests according to the incremental value it obtains from the innovation, which is the difference between the supplier's value with and without an innovation: $V_1^s - V_0^s(w)$. This value difference induces a *replacement effect* (Arrow, 1962) in that the supplier is less willing to invest in R&D when the supplier has less to gain from the innovation (i.e., when the pre-innovation value $V_0^s(w)$ is high relative to V_1^s).

Understanding the replacement effect at play, the monopsonist can influence the supplier's R&D investment via its choice of input price w. Specifically, the monopsonist can change w to affect the supplier's pre-innovation value, $V_0^s(w)$, and manipulate the replacement effect faced by the supplier. Using implicit differentiation and the envelope theorem, we can compute

[5] While V_1^s depends on w_1, we drop w_1 as an argument of the function for brevity.

the impact of the input price w on the supplier's R&D investment:

$$\frac{\partial x^*(w)}{\partial w} = -\frac{1}{\kappa''(x^*(w))}\frac{\partial V_0^s(w)}{\partial w} = \frac{-\pi_s'(w)}{\kappa''(x^*(w))(r+x^*(w))} < 0. \tag{7}$$

That is, an increase in the input price leads to a lower R&D investment. Why? An increase in the input price raises the supplier's pre-innovation profit flow by $\pi_s'(w)$, which benefits the supplier until the innovation arrives, causing a value increase of $\pi_s'(w)/(r + x^*(w))$. This increase in $V_0^s(w)$ decreases the incremental rent of an innovation in equation (6), which results in a decrease in the incentives to innovate.[6]

Consider now the monopsonist's problem of choosing the optimal w for the pre-innovation phase of the game. At every instant of time, it solves

$$rV_0^m = \max_w\{R_0(q(w)) - w \cdot q(w) + x^*(w)(V_1^m - V_0^m)\},$$

where the monopsonist's value at instant t equals its revenue flow, minus the total cost of its inputs, plus the incremental value of an innovation $V_1^m - V_0^m$, which arrives at a rate $x^*(w)$. Using the first-order condition and $\pi_s'(w) = q(w)$, we obtain

$$R_0'(q(w)) = w\left(1 + \frac{1}{e^s(w)} + \frac{\varphi(w)}{e^s(w)}\right), \quad \text{where} \quad \varphi(w) = \frac{V_1^m - V_0^m}{(r + x^*(w))\kappa''(x^*(w))} > 0. \tag{8}$$

Equation (8) captures the monopsonist's incentives to price in the presence of an innovation project. As before, the monopsonist's optimal input price is the one where marginal revenue equals marginal cost. The marginal cost consists of three terms. The first two correspond to the traditional marginal costs of the monopsonist, as discussed in equation (4). The third term captures that the gain in future value $V_1^m - V_0^m$ is delayed when increasing w as a result of a decrease in the rate of innovation (i.e., $\partial x^*/\partial w < 0$). That is, a higher input price increases the revenue of the monopolist but it also increases the per-unit price paid for the input and decreases the supplier's incentives to invest in R&D. We call the optimal dynamic pricing decision w_d.

Figure 1 plots both sides of equation (8) and illustrates the solution w_d. Compared with the monopsonist's marginal cost in the absence of innovation, the marginal cost under the possibility of an upstream innovation is larger by a factor of $w\varphi(w)/e^s(w) > 0$. This term captures how an increase in w delays the innovation benefits accrued by the monopsonist as a result of decreased R&D incentives. This delay shifts the marginal cost curve upwards,

[6] The factor $1/\kappa''(x^*)$ simply translates the change in incremental rents to changes in the arrival rate via the R&D cost function.

inducing the monopsonist to always set an input price that is lower than without innovation. That is, the possibility of an upstream innovation induces the monopsonist to squeeze the supplier with a lower w, decreasing the supplier's pre-innovation value $V_0^s(w)$ and boosting its R&D incentives.[7]

Proposition 1. *The optimal input price set by a monopsonist when the supplier has an innovation project is lower than the input price set by a monopsonist when the supplier does not have an innovation project. That is,* $w_d < w_0$.

To conclude, we observe that squeezing, although productive in incentivizing innovation, is costly in terms of static efficiency. As Figure 1 shows, squeezing the supplier pushes the output choice q_d further away from the efficient quantity q_0^e, lowering the short-run profit flow of both the supplier and monopsonist.

Discussion of Assumptions

Post-innovation Price-taking Behavior. In the model, we assume that the supplier is a price taker, which captures a supplier that lacks bargaining power (e.g., the input is a commodity that can be supplied by multiple firms). One may argue that this is a strong assumption for the post-innovation subgame, as innovation puts the supplier in a position in which it is no longer replaceable, as it is the only firm able to supply the new input (e.g., due to intellectual property protection). Innovation can thus change the bargaining position of the supplier. We note that our results, in particular Proposition 1, hold true for all post-innovation profit streams of the supplier (i.e., rV_1^s) in which innovation benefits the supplier (i.e., $V_1^s - V_0^s(w) > 0$ in equilibrium). That is, post-innovation price taking behavior is not central to our results.[8]

Non-linear Contracts. Although linear contracts are ubiquitous, these are inefficient and do not allow the monopsonist to exert its market power fully. In Section B.1 in the Online Appendix, we show that squeezing also arises in the context of efficient non-linear contracts.

Hold-up Problem. In Section B.2 in the Online Appendix, we relax the assumption that the arrival of the innovation is verifiable by outside parties. In particular, we assume that the supplier and monopsonist can verify the arrival of the innovation, but third parties cannot, making an innovation-contingent contract unenforceable in court. This implies that supplier might be subject to a hold-up problem (Williamson, 1975; Klein *et al.*, 1978; Williamson, 1979), which means that after the arrival of the innovation, the monopsonist may change the terms of the contract to expropriate the supplier's rent.

[7] The figure also shows that $w_1 > w_0$ because the innovation increases the marginal rent that the monopsonist derives from the input while keeping the marginal cost curve fixed.

[8] We thank a Referee for making this observation.

To study such incentives, we extend the model to allow for a sequence of innovations for the supplier to undertake.[9] In this context, we show conditions under which the monopsonist never chooses to deviate to extract the full surplus of any future innovation (i.e., "hold up" the supplier), as this would make innovation incentives vanish, stopping the innovation process.

3 Upstream Innovation and the Firms' Boundaries

The inefficiency introduced by the squeezing effect raises the question of whether a split vertical structure is stable in the presence of the innovation project. Or in other words, whether the impact of squeezing on efficiency is motive to redraw the boundaries of the firms along the vertical supply chain. We consider a deviation from the baseline vertical structure and examine the supplier and downstream firms' incentive to vertically integrate (i.e., all activities performed by a single firm).

In what follows, we make three functional assumptions to obtain analytical results:

Assumption 1. *(i)* $R_i(q) = \alpha^i \cdot q$*, where* $\alpha > 1$ *is interpreted as the magnitude of the innovation; (ii)* $c(q) = q^2/2$*, and; (iii)* $\kappa(x) = x^2/2$*.*

Assumption 1 (i) is somewhat innocuous: as equation (8) shows, the squeezing incentive is driven by the the costs side. Assumption 1 (ii) and (iii) impose a particular structure to the supply functions of the input and R&D, which feed into the monopsonist's marginal costs. However, numerical analysis suggests that the findings below are robust.

We also assume that vertical integration may lead to bureaucracy costs of performing and organizing all activities within a single firm (Coase, 1937), where we model the bureaucracy costs of vertical integration as a flow cost K that is paid at every instant of time in which the firms are integrated.

Baseline Solution Using the first-order condition in equation (6) and Assumption 1 (iii), we obtain $x^*(w) = V_1^s - V_0^s(w)$. Plugging this expression for $x^*(w)$ into equation (5), we can solve for the supplier's pre-innovation value $V_0^s(w)$, and obtain the pace of innovation as a function of the input price w:[10]

$$x^*(w) = \sqrt{r^2 + 2\Delta_s(w)} - r, \tag{9}$$

[9] Other articles modelling sequential innovations include Grossman and Helpman (1991); Aghion and Howitt (1992); Aghion *et al.* (2001); Hopenhayn *et al.* (2006); Segal and Whinston (2007); Parra (2019).

[10] Complete analytical solutions are presented in the Online Appendix.

where $\Delta_s(w) \equiv \pi^s(w_1) - \pi^s(w)$ is the incremental profit flow earned by the supplier when achieving the innovation. Following similar steps, we can solve for the monopsonist's incremental value, $V_1^m - V_0^m$. Replacing the incremental value into the monopsonist's optimal pricing condition in equation (8) we obtain

$$1 = 2w + \frac{w(\alpha^2/4 - (w - w^2))}{(\alpha^2/4 + r^2 - w^2)}. \tag{10}$$

This third-degree polynomial has three analytic solutions, but only one of them imply positive profits, quantities, and prices. We call this solution w_d, which is a function of the only two parameters of the model: α and r.

Lemma 1. *The optimal dynamic input price set by the monopsonist $w_d \in (1/3, 1/2]$ is decreasing in α and increasing in r, where α is the magnitude of the innovation, as defined in Assumption 1.*

The dynamic input price w_d decreases in the magnitude of the innovation. As the innovation becomes more valuable, there are more incentives to squeeze the supplier, inducing a faster pace of innovation. Similarly, as the discount rate increases, the future innovations are worth less, creating less incentive to squeeze the supplier. The input price converges to $w_0 = 1/2$ when the value of the innovation goes to zero ($\alpha = 1$) and has a lower bound of 1/3, where the incentive to squeeze the supplier is at its highest point.

Vertical Integration We next consider whether the supplier and monopsonist would want to vertically integrate (i.e., all activities conducted by a single firm).

At every instant of time, the vertically-integrated firm chooses its input quantity and R&D investment:

$$rV_0^{vi} = \max_{q,x}\{R_0(q) - c(q) - \kappa(x) + x(V_1^{vi} - V_0^{vi})\}, \tag{11}$$

where the flow value of the integrated firm before the innovation arrives equals the full surplus generated by the supply chain plus the incremental value of an innovation, arriving at rate x, net of R&D costs. The firm chooses to produce the efficient input quantity, q_i^e. The instantaneous profit under technology i is given by $\pi_i^{vi} \equiv R_i(q_i^e) - c(q_i^e)$ and the post-innovation value by $rV_1^{vi} = \pi_1^{vi}$. The first-order condition with respect to the R&D investment is $x_{vi} = V_1^{vi} - V_0^{vi}$. Plugging this expression for x_{vi} into equation (11), we can solve for the value of the vertically-integrated firm as well as the equilibrium R&D investment:

$$x_{vi} = \sqrt{r^2 + 2\Delta_{vi}} - r, \tag{12}$$

where $\Delta_{vi} = \pi_1^{vi} - \pi_0^{vi}$ is the incremental profit flow that the supplier earns when achieving the innovation.

How do market outcomes compare with and without vertical integration? Comparing the pace of innovation under both vertical structures (see equations (9) and (12)) amounts to comparing the values of the supplier's incremental profit flows achieved with the innovation, which are depicted in Figure 2 (i.e., Δ_{vi} is the light-shaded area and $\Delta_s(w_d)$ is the dark-shaded area). It turns out that when the magnitude of the innovation and discounting are both small, $\Delta_s(w_d)$ can be larger than Δ_{vi}. To see this, note that as α decreases towards one (no innovation), the rents in the lightly-shaded decrease proportionally to α, as $R_1'(q) = \alpha$. In contrast, while the dark-shaded area decreases when α approaches 1, it increases as r gets small. The latter effect is driven by how a smaller r intensifies the monopsonist's cost of delaying innovation, captured by $\varphi(w)$ in equation (8). Although a small interest rate increases the rents of R&D with and without vertical integration, it also increases the supplier's discouragement effect, which leads to a decrease in R&D (see equation 7). The monopsonist responds by increasing $\Delta_s(w_d)$ to counter this change in the supplier's replacement effect. Given α, a smaller r increases $\Delta_s(w_d)$, while leaving Δ_{vi} unchanged.

Proposition 2. *For a small innovation (i.e., an α close to 1, where α is the magnitude of the innovation, as defined in Assumption 1), there exists a discount rate r such that the vertically-independent supplier makes a greater R&D investment than the fully-integrated firm; i.e., $x^*(w_d) > x_{vi}$.*

Despite the potential for a faster speed of innovation in the absence of vertical integration, the supplier and monopsonist can achieve a larger joint value by vertically integrating as long as the bureaucracy costs of performing and organizing all activities within a single firm are sufficiently low (Coase, 1937), where the bureaucracy costs of vertical integration are modelled as a flow cost K that is paid at every instant of time in which the firms are integrated. The potential for a greater joint value stems from the fact that the squeezing incentive causes inefficiencies in production and R&D, which imply a loss in joint value.

We consider bureaucracy costs that are sufficiently high that the supplier and monopsonist would choose to remain independent in the absence of an innovation project (or when the squeezing incentive is not present). Formally, we consider bureaucracy costs that are larger than $\hat{K}$, which is defined as $\hat{K} = \pi_0^{vi} - (\pi_0^m + \pi_s(w_0))$. In such high-bureaucracy costs situations, when does the squeezing incentive motivate the monopsonist and supplier to vertically integrate? The following proposition shows that the firms do not have an incentive to integrate unless the magnitude of the innovation α is sufficiently large. That is, if in the absence of the squeezing effect the firms would not want to integrate, the inefficiencies caused

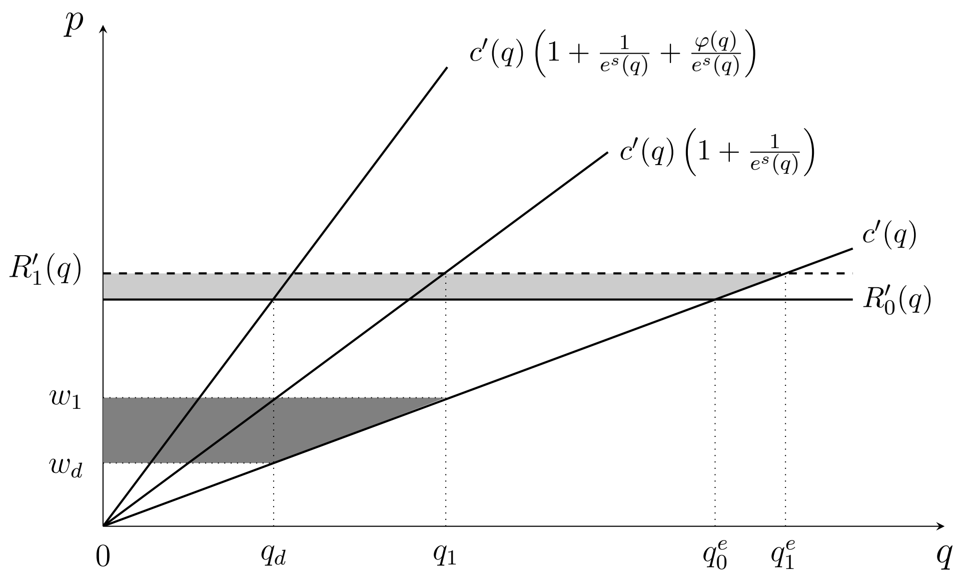

Figure 2: Innovation incentives and boundaries of the firm. Depiction of the marginal revenue curves (before and after the innovation) and the marginal cost curves in the static monopsony case (see equation (4)) and in the monopsony case with squeezing (see equation (8)). The light-shaded area illustrates the innovation incentives of a vertically integrated firm, $\Delta_{vi} = \pi_1^{vi} - \pi_0^{vi}$. The dark-shaded area represents the innovation incentives of a squeezed supplier, $\Delta_s(w_d) = \pi_s(w_1) - \pi_s(w_d)$.

by the squeezing effect do not justify vertical integration unless the value of the innovation is sufficiently high. This suggests that vertical independence of the supplier and monopsonist is a stable vertical arrangement as long as the size of the innovation is small.

Proposition 3. *For every cost $K > \hat{K}$, there exist thresholds $\underline{\alpha}$ and $\bar{\alpha}$, where $1 < \underline{\alpha} \leq \bar{\alpha}$, such that the firms choose not to vertically integrate when $\alpha < \underline{\alpha}$ and to vertically integrate when $\alpha > \bar{\alpha}$, and where α is the magnitude of the innovation, as defined in Assumption 1.*[11]

4 Conclusions

A monopsonist can enhance a supplier's R&D incentives by strategically decreasing the short-run profit flow of the supplier (i.e., squeezing) to lessen the supplier's Arrow's replacement effect. The monopsonist achieves a higher pace of innovation by distorting its trade volume with the supplier despite an efficiency loss. While the efficiency loss caused by this practice may be grounds for vertical integration, we show that vertical integration only occurs when

[11]Simulations lead us to believe that the value of vertically integrating is increasing in α; i.e., there should be a unique value $\alpha^* > 1$ such that vertical integration occurs if and only if $\alpha > \alpha^*$. However, the lack of an analytical solution for w_d precludes us from proving such a general statement.

the magnitude of the innovation is sufficiently large, which is when the efficiency loss of squeezing is most severe. These results combined can rationalize two facts in our motivating examples: i) downstream firms with a dominant position in innovative industries squeeze their suppliers, ii) the vertical structure (i.e., vertical independence between the downstream firm and the supplier) is stable despite the inefficiency caused by squeezing.

Appendix

Proof of Proposition 1 $R_1(q) > R_0(q)$ imply $\pi_0^m < R_1(q(w_0)) - w_0 \cdot q(w_0) < \pi_1^m$; which, in turn, implies that $V_1^m > V_0^m$. Consequently, $\varphi(w) > 0$ and the right-hand side of (8) is always larger than the right-hand side of (4), proving the result. □

Proof of Lemma 1 Using first-order condition (10) define w_d as the price that solves $\Gamma(w_d, \alpha, r) = 0$, where

$$\Gamma(w, \alpha, r) = (1 - 2w)(\alpha^2/4 + r^2 - w^2) - w(\alpha^2/4 + w^2 - w).$$

When no innovation exists ($\alpha = 1$) $w_d = w_0 = 1/2$. Implicitly differentiating w_d, we obtain

$$\frac{\partial w_d}{\partial \alpha} = -\frac{\alpha(3w_d - 1)}{4r^2 + 3\alpha^2/2 - 6w_d^2} \qquad \text{and} \qquad \frac{\partial w_d}{\partial r} = \frac{4r\alpha(1 - 2w_d)}{4r^2 + 3\alpha^2/2 - 6w_d^2}. \tag{13}$$

When $\alpha = 1$, $\partial w_d/\partial \alpha = -1/(8r^2)$, implying that w_d decreases in α in a neighborhood of $\alpha = 1$. Using the implicit derivative, we can see that this decrease implies that w_d is always decreasing in α and has an asymptote at $w_d = 1/3$. These observations also imply $\partial w_d/\partial r > 0$. □

Proof of Proposition 2 We show that $\Delta^s(w_d) - \Delta^{vi} = (4 - 3\alpha^2 - 4w_d^2)/8 > 0$ for small α and r. When $\alpha = 1$, $w_d = 1/2$ and $\Delta^s(w_d) - \Delta^{vi} = 0$. Differentiating with respect to α and then evaluating when $\alpha = 1$, we obtain

$$\left.\frac{\partial(\Delta^s(w_d) - \Delta^{vi})}{\partial \alpha}\right|_{\alpha=1} = -\frac{1}{4}\left.\left(3\alpha + w_d\frac{\partial w_d}{\partial \alpha}\right)\right|_{\alpha=1} = \frac{1}{4}\left(\frac{1}{16r^2} - 3\right),$$

where we used (13) evaluated at $\alpha = 1$. The derivative is positive for small enough r. □

Proof of Proposition 3 The firms vertically integrate whenever $V^{vi} - V_0^m - V_0^s(w_d) > K/r$.[12] When $\alpha = 1$, $V^{vi} - V_0^m - V_0^s(w_d) = \hat{K}/r$. When $\alpha \to \infty$, the values V^{vi}, V_0^m, and $V_0^s(w_d)$ become unboundedly large. Because $\lim_{\alpha\to\infty} V^{vi}/(V_0^m + V_0^s(w_d)) = 4/3$ the difference $V^{vi} - (V_0^m + V_0^s(w_d))$ diverges, and vertically integration can occur for any integration cost $K > \hat{K}$. Taken together, these results imply that, by the intermediate value theorem, there exist thresholds $\underline{\alpha}$ and $\overline{\alpha}$, such that for every $K > \hat{K}$ integration does not occur if $\alpha < \underline{\alpha}$ and does occur if $\alpha > \overline{\alpha}$.

[12] For value functions, see Online Appendix or construct using $x^*(w)$ and x_{vi} in equations (9) and (12).

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Supplemental Material – Intended for Online Publication

Monopsony Power and Upstream Innovation

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A Analytic Solutions

For completeness, in this online appendix, we present the complete analytic solutions to the model in Section 3. All relevant information to prove the results in the article is in the main appendix of the paper.

A.1 Boundaries of the Firms

Baseline model Under assumptions (i) and (ii) one can verify that: $w_i = q_i = \alpha^i/2$ (see equation 4), $\pi_s(w_i) = \alpha^{2\cdot i}/8$ (see equation 1), and $\pi_i^m = \alpha^{2\cdot i}/4$ (see equation 3). Using the first-order condition in equation (6) and assumption (iii), we obtain $x^*(w) = V_1^s - V_0^s(w)$. Plugging this expression for $x^*(w)$ into equation (5), we can solve for the supplier's pre-innovation value $V_0^s(w)$ and the pace of innovation as a function of the input price w:

$$V_0^s(w) = r + \frac{\pi_s(w_1)}{r} - \sqrt{r^2 + 2\Delta_s(w)} \qquad \text{and} \qquad x^*(w) = \sqrt{r^2 + 2\Delta_s(w)} - r,$$

where $\Delta_s(w) \equiv \pi^s(w_1) - \pi^s(w)$ is the incremental profit flow earned by the supplier when achieving the innovation. Solving for the monopsonist's pre-innovation value we obtain:

$$V_0^m = \left(w_d - w_d^2 + x^s(w_d)V_1^m\right) \Big/ \left(x^s(w_d) + r\right).$$

Using the previous equation and the optimal R&D investment, we can solve for the monopsonist's incremental value of an innovation, $V_1^m - V_0^m$, which we replace into the the monopsonist's optimal pricing condition in equation (8) to obtain

$$1 = 2w + \frac{w(\alpha^2/4 - (w - w^2))}{(\alpha^2/4 + r^2 - w^2)}.$$

This third-degree polynomial has three analytic solutions, but only one of them imply positive profits, quantities, and prices. We call this solution w_d, and is given by:

$$w_d = \frac{i\sqrt{3}-1}{2}C - \frac{i\sqrt{3}+1}{2}\frac{a + \frac{2r^2}{3}}{C}, \quad \text{where} \quad C = \frac{\sqrt[3]{\sqrt{(a+r^2)^2 - 4\left(a + \frac{2r^2}{3}\right)^3} - (a+r^2)}}{\sqrt[3]{2}},$$

$a = \alpha^2/4$, and i represents the imaginary number. Despite having an imaginary component, this solution takes values $w_d \in (1/3, 1/2]$ for every feasible value of α and r.

Vertical Integration In the context of assumptions (i) and (ii), the optimal production is $q_i^e = \alpha^i$, which implies that $\pi_i^{vi} \equiv R_i(q_i^e) - c(q_i^e) = \alpha^{2 \cdot i}/2$ and $rV_1^{vi} = \pi_1^{vi}$. The first-order condition with respect to the R&D investment is $x_{vi} = V_1^{vi} - V_0^{vi}$. Plugging this expression for x_{vi} into equation (11), we can solve for the value of the vertically-integrated firm as well as the equilibrium R&D investment:

$$V_0^{vi} = r + \frac{\pi_1^{vi}}{r} - \sqrt{r^2 + 2\Delta_{vi}} \qquad \text{and} \qquad x_{vi} = \sqrt{r^2 + 2\Delta_{vi}} - r,$$

where $\Delta_{vi} = \pi_1^{vi} - \pi_0^{vi}$ is the incremental profit flow that the supplier earns when achieving the innovation.

B Extensions

In the baseline model, we make two modelling assumptions that we relax in this section. The first is that the monopsonist uses a linear contract in its dealing with the supplier; the second is that arrival of the innovation is verifiable by outside parties, making innovation-contingent contracts enforceable in court.

B.1 Non-linear Contracts

Although linear contracts are ubiquitous, these are inefficient and do not allow the monopsonist to exert its market power fully. We show that squeezing also arises in the context of efficient non-linear contracts. Here we maintain the assumption that the arrival of the innovation is verifiable by outside parties, making innovation-contingent contracts enforceable in court.

Consider a scenario in which the monopsonist asks the supplier to supply the efficient quantity (i.e., q_i^e) in exchange for a fixed transfer t. Without R&D, the monopsonist extracts all the surplus by paying $t_0 = c(q_0^e)$; i.e., the minimal transfer that ensures participation by the supplier. In the presence of R&D, the monopsonist offers and commits to the contract schedule (t_d, t_1), the pre- and post-innovation transfers.

In this context, the post-innovation value of the supplier equals $rV_1^s = t_1 - c(q_1^e)$, which is positive only if $t_1 > c(q_1^e)$. The pre-innovation value of the supplier is then given by

$$rV_0^s(t_d) = \max_x \{t_d - c(q_0^e) - \kappa(x) + x(V_1^s - V_0^s(t_d))\}, \tag{B.1}$$

that is, the flow value of the supplier equals its profit flow (i.e., the transfer) plus the expected gain from an innovation net of R&D costs. Under Assumption 1 (iii), the first-order condition of the supplier's problem becomes $x_n = V_1^s - V_0^s(t_d)$, which we can replace back into equation (B.1) to solve for $V_0^s(t_d)$. Observe that the monopsonist can set a pre-innovation transfer that simultaneously minimizes the replacement effect (i.e., maximizes the supplier's incremental value of the innovation) and extracts all the pre-innovation rents of the supplier, i.e., $V_0^s(t_d) = 0$. This transfer is given by $t_d = c(q_0^e) - (V_1^s)^2/2$ which is lower than $t_0 = c(q_0^e)$

(the benchmark when the monopsonist is unconcerned about R&D). To see this, note that the monopsonist needs to give the supplier rents after the arrival of the innovation for there to be innovation incentives (i.e., $V_1^s > 0$). This allows the monopsonist to backload the supplier's compensation, and squeeze the supplier before the innovation's arrival to maximize R&D incentives.

Proposition B.1. *The optimal transfer set by a monopsonist under an efficient non-linear contract is lower under the possibility of upstream innovation, i.e.,* $t_d < t_0$.

Proof We show that $t_1^* > c(q_1^e)$. Replacing the supplier's optimal R&D investment, $x_n = V_1^s - V_0^s$, into its value function, we can solve for V_0^s. Using $rV_1^s = t_1 - c(q_1^e)$, we find $x_n = \sqrt{r^2 + 2\Delta_n} - r$, where $\Delta_n = t_1 - c(q_1^e) - t_d + c(q_0^e)$.

The monopsonist then solves $rV_0^m = \max_{t_d,t_1}\{R_0(q_0^e) - t_d + x_n(V_1^m - V_0^m)\}$. Using x_n and $rV_1^m = R_1(q_1^e) - t_1$, the problem becomes

$$rV_0^m = \max_{t_d,t_1}\left\{R_0(q_0^e) - t_d + \left(\sqrt{r^2 + 2\Delta_n} - r\right)\left(\frac{R_1(q_1^e) - t_1}{r} - V_0^m\right)\right\}$$

subject to supplier participation constraint $V_i^s \geq 0$. Because $\partial V_0^m/\partial t_d < 0$, the monopsonist wants to make t_d as small as possible. Therefore, the participation constraint at $i = 0$ binds and $t_d^* = c(q_0^e) - (t_1 - c(q_1^e))^2/2r^2$. Differentiating V_0^m with respect to t_1, and evaluating the derivative at t_d^* and $t_1 = c(q_1^e)$ (i.e., the lower transfer satisfying the supplier participation constraint), we obtain $\partial V_0^m/\partial t_1 = (R_1(q_1^e) - c(q_1^e) - rV_0^m)/r > (V_1^m - V_0^m) > 0$, proving $t_1^* > c(q_1^e)$. □

B.2 Hold-up Problem

We next relax the assumption that the arrival of the innovation is verifiable by outside parties. In particular, we assume that the supplier and monopsonist can verify the arrival of the innovation, but third parties cannot, making an innovation-contingent contract unenforceable in court. This implies that supplier might be subject to a hold-up problem (Williamson, 1975; Klein *et al.*, 1978; Williamson, 1979), which means that after the arrival of the innovation, the monopsonist may change the terms of the contract to expropriate the supplier's rent.

To study such incentives, we extend the model to allow for a sequence of innovations for the supplier to undertake.[13] In this context, we show conditions under which the monopsonist never chooses to deviate to extract the full surplus of any future innovation (i.e., "hold up" the supplier), as this would make innovation incentives vanish, stopping the innovation process.

Let $i \in \{0, 1, 2, \ldots\}$ be an index denoting the number of innovations that have occurred. For tractability, we modify the previous model by assuming:

Assumption B.1. *i)* $R_i(q) = \alpha^i q$, *where* α *is the size of each innovation and* $i \in \{0, 1, 2, \cdot\}$; *ii)* $c_i(q) = \alpha^i q^2/2$; *and iii)* $\kappa_i(x) = \alpha^i x^2/2$.

[13] Other articles modelling sequential innovations include Grossman and Helpman (1991); Aghion and Howitt (1992); Aghion *et al.* (2001); Hopenhayn *et al.* (2006); Segal and Whinston (2007); Parra (2019).

That is, both revenue and costs increase proportionally to the innovation magnitude.

In this context, after i innovations have occurred, the first-order condition of the supplier's production problem (i.e., equation 1) becomes $w_i = \alpha^i q$. Given input price w_i, the supplier also solves

$$rV_i^s(w_i) = \max_{x_i}\{\pi_i^s(w_i) - \kappa(x_i) + x_i(V_{i+1}^s(w_{i+1}) - V_i^s(w_i))\},$$

where the flow value of a supplier after i innovations equals the supplier's profit flow plus the incremental rent of an innovation net of R&D costs. The first-order condition of this problem is $x_i(w_i, w_{i+1}) = (V_{i+1}^s(w_{i+1}) - V_i^s(w_i))/\alpha^i$, with $\partial x_i/\partial w_i = -w_i/((\alpha^i)^2(r + x_i)) < 0$.

Similarly, the monopsonist's problem consists of choosing an input price that solves

$$rV_i^m = \max_{w_i}\left\{w_i - \frac{w_i^2}{\alpha^i} + x_i(w_i)(V_{i+1}^m - V_i^m)\right\},$$

where we use that $\pi_i^m(w) = w_i - w_i^2/\alpha^i$. Using the expression for $\partial x_i/\partial w_i$, the first-order condition of this problem becomes

$$1 - \frac{w_i}{\alpha^i}\left(2 + \frac{V_{i+1}^m - V_i^m}{\alpha^i(r + x_i)}\right) = 0. \tag{B.2}$$

We solve the game by making two conjectures that are verified in equilibrium: i) that the sequence of optimal prices is such that the input price increases at rate α with every innovation (i.e., $w_i = \alpha^i w_d$), and ii) that the equilibrium of the game features values of the form $V_i^j = \alpha^i V_0^j$ for $j \in \{m, s\}$. Using these conjectures, we find that equation (B.2), for every i, collapses to finding the price w_d that solves

$$1 - 2w_d \underbrace{- w_d \frac{\alpha - 1}{r + x_{seq}} V_0^m}_{\text{squeezing effect}<0} = 0, \tag{B.3}$$

where $x_{seq} = (\alpha - 1)V_0^s$ is the innovation rate, which is independent of the number of innovations i, and the firms' values are given by

$$V_0^s = \frac{1}{(\alpha - 1)^2}\left(r - \sqrt{r^2 - 2(\alpha - 1)^2\pi_s(w_d)}\right) \qquad \text{and} \qquad V_0^m = \frac{\pi_0^m}{r - x_{seq}(\alpha - 1)}. \tag{B.4}$$

As the first-order condition shows, the squeezing effect exerts a downward pressure on pricing incentives, causing w_d to be lower than the price set by a monopsonist ignoring innovation effects.[14] The monopsonist then chooses a path of prices given by $w_i = \alpha^i w_d$.

As a benchmark, consider the pricing problem of a monopsonist that seeks to maximize its static profit, ignoring the impact of the input price on R&D incentives. The monopsonist would choose $w_i^{static} = \arg\max \pi_i^m(w) = \arg\max w_i - w_i^2/\alpha^i = \alpha^i/2$. When $i = 0$, $w_0^{static} =$

[14] We note that this solution is only defined for $r > \alpha - 1$. For larger values of α, the payoff growth associated caused by the innovations is too high and the values of the supplier and monopsonist diverge to infinity.

1/2 and one can verify that $w_0^{static} = 1/2$ does not satisfy equation (B.3), as the left-hand size is negative because of the squeezing effect. That is, the forward-looking monopsonist has an incentive to set a price that is lower than w_0^{static} because of its impact on R&D incentives. Because the forward-looking monopsonist sets $w_i = \alpha^i w_d$ for every technology state i, then $w_i < w_i^{static}$ for every i.

The result that dynamic input prices are lower than the static one also implies that the innovation rate under price squeezing is lower than the innovation under static input prices (when the monopsonist ignores R&D in its pricing decision). That is, $x(w_i, w_{i+1}) < x(w_i^{static}, w_{i+1}^{static})$ for every i. This result follows from $x_{seq} = (\alpha - 1)V_0^s$ for every i and V_0^s being increasing in w (see equation (B.4)). The monopsonist gains from suppressing w to incentivize innovation (conditional on future values of w). These gains of input price suppression, however, exist in every period, leading to a suppression along the full path of prices $\{w_i\}$, decreasing the pace of innovation in the long run.

Would the monopsonist want to deviate from its sequence of prices to extract the full surplus generated by any future innovation? In this case, the monopsonist would earn the total surplus generated by the supply chain when production decisions are efficient (i.e., where q solves $R_i'(q) = c_i'(q)$) for every innovation. That is, $V_i^{dev} = \pi_i^{vi}/r = \alpha^i \pi_0^{vi}/r$. The following proposition shows that the monopsonist would not make such a deviation when the discount rate is sufficiently small (i.e., the benefits of future innovations are not heavily discounted) or when the innovation size is large (i.e., the benefits of future innovations are large). That is, in such cases, it is in the monopsonist's best interest to preserve innovation incentives.

Proposition B.2. *For a sufficiently small interest rate r or a sufficiently high innovation magnitude α, hold up does not arise in equilibrium. That is, $V_i^m > V_i^{dev}$ for every i.*

Proof At any innovation i, maintaining the innovation process is preferred by the monopsonist over full surplus extraction if $V_i^{dev} < V_i^m$ or equivalently,

$$\pi_0^{vi} < r\pi_0^m \Big/ \sqrt{r^2 - 2(\alpha - 1)^2 \pi_s(w_d)}\ .$$

This condition holds if r is sufficiently small or α is sufficiently large. □