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Optimal cross-holdings and upstream R&D*

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Abstract

While cross-holdings are widely observed, their degree varies across industries. We show that upstream R&D is one possible reason. In a vertically related market with two downstream firms and an upstream firm engaging in cost-reducing R&D, the cross-holding rate is determined through Nash bargaining. The equilibrium rate maximizes downstream joint profit and is always below the merger level. An interior optimum exists only when upstream R&D is sufficiently inefficient, and the rate decreases with R&D efficiency and market size. In the linear-quadratic case, any degree of cross-holdings can arise. Since total surplus falls with cross-holdings, the private optimum is socially excessive, justifying antitrust intervention.

JEL codes: L13, D43, O32.

Keywords: Cross-holdings, vertical structure, R&D, optimal choice.

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1 Introduction

It is well known that cross-holdings, where firms hold passive equity stakes in their rivals, soften competition and harm consumer welfare. By giving a firm a share in its rival's profits, cross-holdings reduce the incentive to compete aggressively, leading to higher prices and lower output (Reynolds and Snapp, 1986; Bresnahan and Salop, 1986; O'Brien and Salop, 2000; Gilo et al., 2006). However, these studies treat the degree of cross-holdings as exogenously given. In reality, cross-holdings are the result of deliberate strategic choices by firms, and the observed degree varies considerably across industries. Some firms hold substantial stakes in their rivals, while others hold none. This raises fundamental questions: Why do some industries exhibit high degrees of cross-holdings while others exhibit none? What determines the equilibrium level of cross-holdings? Understanding the endogenous determination of cross-holding rates is essential for antitrust authorities to predict when and where cross-holdings are likely to emerge and to design appropriate policy responses.

This paper proposes that upstream R&D efficiency is a key determinant of downstream cross-holdings. We construct a three-stage game with an upstream monopolist and two downstream Cournot competitors. In the first stage, downstream firms negotiate the cross-holding rate through Nash bargaining with side payment. In the second stage, the upstream firm chooses its cost-reducing R&D investment and input price. In the third stage, downstream firms compete in quantities. Hu et al. (2022) shows a similar problem without our first stage for the optimal endogenous choice of crass-holding rate.

Our analysis yields four main findings. First, we show the existence of an interior optimal cross-holding rate. When the upstream firm's R&D cost function is highly convex (meaning that R&D is very costly and thus inefficient), the upstream firm invests little regardless of market conditions, so the negative indirect effect of cross-holdings on downstream profits through higher input prices is small. Downstream profit then increases with the cross-holding rate from zero but decreases as the rate approaches full merger, guaranteeing an interior optimum between zero and one. When R&D is highly efficient (low R&D cost convexity), downstream profit decreases with the cross-holding rate for all values, and the optimal choice is no cross-holdings. Second, full merger is never optimal. We show that the optimal cross-holding rate is always strictly less than the level that would correspond to a full horizontal merger, provided that the upstream firm engages in positive R&D investment. A full merger would eliminate downstream competition, drastically reducing upstream input demand and destroying upstream R&D incentives, leading to a higher input price that harms downstream profits. Third, the optimal cross-holding rate decreases with upstream R&D efficiency and increases with downstream market size. More efficient R&D amplifies the negative indirect effect, making cross-holdings less attractive. A larger market similarly increases upstream responsiveness, also reducing the optimal cross-holding rate. Fourth, any degree of cross-holdings can arise in equilibrium in the linear-quadratic case. The optimal cross-holding rate takes every value from zero to one, rationalizing the wide variation observed across industries. A key implication is that intervention is not always warranted: when the market is large or upstream R&D is efficient, the private optimum is zero and no policy action is required.

There is a large body of research on the competitive effects of cross-holdings (Reynolds and Snapp, 1986; Farrell and Shapiro, 1990; Fanti, 2013, 2015, 2016; Shuai et al., 2018; López and Vives, 2019; Hu et al., 2022), which generally find that cross-holdings reduce competition but may have ambiguous welfare effects. These studies, however, treat cross-holdings as exogenous. By contrast, the literature analyzing endogenous cross-holdings is very limited (Flath, 1991; Clayton and Jorgensen, 2005; Ghosh and Morita, 2017; Li et al., 2015; Ma et al., 2021). Flath (1991) shows that firms competing in quantity do not acquire silent interests in rivals, while Clayton and Jorgensen (2005) find that the equilibrium degree of cross-holdings is a short position if products are substitutes. Ghosh and Morita (2017) examine knowledge transfer through partial equity ownership and show that optimal ownership depends on the efficiency of transferred knowledge and the number of firms. Li et al. (2015) show that an incumbent chooses positive cross-holdings to deter entry. Ma et al. (2021) analyze cross-holdings as a commitment device to soften competition. Most recently, Ma and Zeng (2022) study optimal cross-holding in an asymmetric oligopoly and find that firms choose to hold ownership in the most efficient rival.

There are two previous literature considering exogenous cross-holdings in vertical structure with upstream R&D. Hu et al. (2022) analyze the effects of exogenous downstream cross-holdings on upstream R&D and find that cross-holdings may increase downstream producer and total surplus when upstream investment technology is inefficient. Jin et al. (2024) correct the downstream producer surplus definition used in Hu et al. (2022) and show that total surplus always decreases with cross-holdings. None of them consider endogenous cross-holdings.

The remainder of this paper is organized as follows. Section 2 presents the model. Section 3 derives the equilibrium outcomes and characterizes the optimal cross-holding rate. Section 4 concludes.

2 The Model

Our model added the endogenous choice of the cross-holding rate on Hu et al. (2022). Based on the very few literature on endogenous choice of cross-holding rate, we examine this problem through Nash bargaining.

First, we summarize the basic settings that follows Hu et al. (2022). We assume a market with an upstream firm U and two downstream firms i and j ($i, j = 1, 2$ and $i \neq j$). The upstream firm produces input and sells it to the downstream firms at input price w. The downstream firms transform one unit of input into one unit of output at zero marginal cost. The downstream firms produce homogeneous product and compete in quantities. The inverse demand is $p(Q)$, where $Q \equiv q_i + q_j$ is the aggregate output. The inverse demand is continuously differentiable, with $p(Q) > 0$, $p'(Q) < 0$ and a constant curvature, i.e., $z \equiv -Qp''(Q)/p'(Q) < 1$. The assumption on $p(Q)$ imply the following parametric form: $p(Q) = a - bQ^{1-z}/(1-z)$, where $a, b \geq 0$. Then, the operating profit of downstream firm i is $\pi_i \equiv [p(Q) - w]q_i$.

The upstream firm can make investments to reduce own marginal cost c to $c - x$. To reduce the marginal cost by x, the upstream firm incurs investment cost $\Gamma(x)$ where $\Gamma(0) = 0$

and for any $x > 0$, $\Gamma(x) > 0$, $\Gamma'(x) > 0$, and $\Gamma''(x) > 0$. Moreover, we assume the investment cost function has a constant curvature: $t \equiv x\Gamma''(x)/\Gamma'(x)$, where $t > 0$. The assumption on $\Gamma(x)$ imply the following parametric form: $\Gamma(x) = \gamma x^{t+1}/(t+1)$, where $\gamma, t > 0$. Note that the demand is linear at $z = 0$ and $\Gamma(x)$ takes a quadratic form at $t = 1$. The profit of the upstream firm is $\pi_U \equiv [w - (c - x)]Q - \Gamma(x)$.

Now, we introduce the endogenous choice of the cross-holding rate. Different from Hu et al. (2022) where an exogenous symmetric cross-holding rate were considered, we consider cross-holdings in the downstream market where downstream firm i has $s_i \in [0, 1)$ percent of the equity of its rival in the form of passive investments with no control rights. The nominal firm value of firm i, v_i, is given by the following expression: $v_i = \pi_i + s_i v_j$. There exists a chain effect (Gilo et al., 2006), hence the nominal value of firm i is rewritten as $v_i = (\pi_i + s_i\pi_j)/(1 - s_i s_j)$. This nominal value diverges to infinity as downstream firm j's ownership stake in downstream firm i approaches one. To remove this inflationary effect, we define the objective function of downstream firm i, V_i, as its real value, obtained by multiplying its nominal value by $(1 - s_j)$:

$$V_i = (1 - s_j)(\pi_i + s_i\pi_j)/(1 - s_i s_j). \tag{1}$$

With this real firm value specification, downstream producer surplus is defined as the sum of firms' operating profits: $PS^D = V_i + V_j = \pi_i + \pi_j$. This assumption of PS^D follows Jin et al. (2024) that pointed out the inflated expression of downstream producer surplus of Hu et al. (2022). However, Jin et al. (2024) also consider exogenous symmetric cross-holding rate, hence the form of V_i is different from (1). We then assume that PS^D is concave in (s_i, s_j).

To implement the cross-ownership structure (s_i, s_j), downstream firm j makes a side payment m to downstream firm i. The variables (s_i, s_j) are determined through Nash bargaining. Let β denote the bargaining power of downstream firm i, and $1-\beta$ that of downstream firm j. We assume that, if bargaining breaks down, the cross-ownership arrangement cannot be implemented. Consequently, each firm's disagreement payoff is given by its equilibrium profit when $s_i = s_j = 0$, denoted by V_0.

The timing of the game is as follows. At stage 1, downstream firms determine the degree of cross-ownership (s_i, s_j) and the level of the side payment m through Nash bargaining. At stage 2, the upstream firm U decides the investment level x and the input price w. At stage 3, the downstream firms compete in quantity. Using backward induction, we solve this game.

3 Analysis

3.1 Stage 3: Output decision by downstream firms

At stage 3, by the first-order conditions, $\partial V_i/\partial q_i = 0$ and $\partial V_j/\partial q_j = 0$, the downstream output are

$$q_i(w, s_i, s_j) = -\frac{(1-s_i)[p(Q)-w]}{(1-s_is_j)p'(Q)}, \quad q_j(w, s_j, s_i) = -\frac{(1-s_j)[p(Q)-w]}{(1-s_is_j)p'(Q)}. \tag{2}$$

Since total output $Q(w, s_i, s_j)$ is symmetric in the degree of cross-ownership (s_i, s_j), the upstream firm's input demand is also symmetric in (s_i, s_j). As a result, downstream producer surplus PS^D is also symmetric in (s_i, s_j). Moreover, since downstream producer surplus is concave in (s_i, s_j), if a maximizer exists, at least one maximizer must satisfy $s_i = s_j$. As will be shown later, at stage 1, (s_i, s_j) is chosen to maximize downstream producer surplus. Therefore, without loss of generality, we can restrict attention to symmetric ownership structures, $s_i = s_j = s$.

Under symmetric cross-ownership, $s_i = s_j = s$, the downstream output is

$$q_i(w, s) = -\frac{p(Q)-w}{(1+s)p'(Q)}. \tag{3}$$

Differentiating $Q(w,s) = 2q_i(w,s)$ with respect to w and/or s, we have

$$\frac{\partial Q(w,s)}{\partial w} = \frac{2}{\xi p'(Q)} < 0, \quad \frac{\partial Q(w,s)}{\partial s} = \frac{2[p(Q)-w]}{(1+s)\xi p'(Q)} < 0 \tag{4}$$

where $\xi \equiv (1-z)(1+s)+2 > 2$ because of $z < 1$.

3.2 Stage 2: Investment level and input price by upstream firm

At stage 2, the upstream firm decides w and x. The first-order conditions are

$$\frac{\partial \pi_U(w,x)}{\partial w} = Q + \frac{2(w-c+x)}{\xi p'(Q)} = 0, \quad \frac{\partial \pi_U(w,x)}{\partial x} = Q - \Gamma'(x) = 0. \tag{5}$$

Then, the input price w and the investment level x are obtained as

$$w(s) = \frac{1}{2}Q(s+1)p'(Q) + p(Q), \quad x(s) = c - \frac{1}{2}Q(\xi+1+s)p'(Q) - p(Q). \tag{6}$$

Given $\partial^2\pi_U(w,x)/\partial x^2 = -\Gamma''(x) < 0$, the second-order necessary condition $\partial^2\pi_U(w,x)/\partial w^2 \cdot \partial^2\pi_U(w,x)/\partial x^2 - [\partial^2\pi_U(w,x)/\partial w\partial x]^2 > 0$ is satisfied if $\psi^{SOC} \equiv -2x - t(2-z)\xi p'(Q)\Gamma'(x) > 0$, that is,

$$t > -\frac{2x}{(2-z)\xi p'(Q)\Gamma'(x)} \equiv t^{SOC}. \tag{7}$$

Differentiating the first-order conditions for the upstream firm with respect to s, and using the above outcomes, we can obtain

$$w'(s) = -\frac{Qxp'(Q)}{\psi^{SOC}} > 0, \quad x'(s) = \frac{Qx(2-z)p'(Q)}{\psi^{SOC}} < 0. \tag{8}$$

3.3 Stage 1: Optimal degree of cross-holdings

Now, we can analyze our main results, that is, the choice of the optimal cross-holding rate s at stage 1. Nash product is given by $NP = \beta\log(V_i + m - V_0) + (1-\beta)\log(V_j - m - V_0)$.

The first-order condition for m leads to

$$m^* = V_0(1-2\beta) - (1-\beta)V_i + \beta V_j.$$

Substituting m^* into NP, we obtain $NP = \beta \log[\beta(PS^D(s_i, s_j) - 2V_0)] + (1-\beta)\log[(1-\beta)(PS^D(s_i, s_j) - 2V_0)]$, where $PS^D(s_i, s_j)$ is the downstream producer surplus at stage 1. The first-order conditions for s_i and s_j are as follows.

$$\frac{\partial NP}{\partial s_i} = \frac{1}{PS^D(s_i, s_j) - 2V_0}\frac{\partial PS^D(s_i, s_j)}{\partial s_i} = 0, \quad \frac{\partial NP}{\partial s_j} = \frac{1}{PS^D(s_i, s_j) - 2V_0}\frac{\partial PS^D(s_i, s_j)}{\partial s_j} = 0.$$

Therefore, Nash bargaining results in the selection of (s_i, s_j) that maximizes PS^D. As noted immediately after equation (**??**), PS^D is symmetric in (s_i, s_j) and, by assumption, is concave in (s_i, s_j). Hence, among the set of maximizers of PS^D, there exists at least one satisfying $s_i = s_j$.

Accordingly, in what follows, we restrict attention to the symmetric case in which $s = s_i = s_j$.

Let $PS^D(w(s), s)$ denote downstream producer surplus after substituting equations (**??**) and (**??**), i.e., $PS^D(w(s), s) = \big[p(Q(w(s), s)) - w(s)\big]Q(w(s), s)$. Differentiating $PS^D(w(s), s)$ with respect to s yields

$$\frac{dPS^D(w(s), s)}{ds} = \frac{\partial PS^D(w, s)}{\partial w}\frac{\partial w(s)}{\partial s} + \frac{\partial PS^D(w, s)}{\partial s}. \tag{9}$$

Incorporating the outcomes obtained above and substituting into (9), standard calculations lead to

$$\frac{dPS^D(w(s), s)}{ds} = \frac{Q^2 p'(Q)[2x + (1-s)(2-z)tp'(Q)\Gamma'(x)]}{2\psi^{SOC}}. \tag{10}$$

This result is same with (12) in Jin et al. (2024), showing again that Nash bargaining with side payments maximizes downstream joint profit, the privately optimal cross-holding rate is the one that maximizes the downstream firms' total profit, regardless of how that profit is distributed between them.

Corner solutions and the condition for interior optimum We first examine the sign of $dPS^D(w(s),s)/ds$ at $s=1$ and at $s=0$. First, substituting $s=1$ into (**??**), we have

$$\left.\frac{dPS^D(w(s),s)}{ds}\right|_{s=1} = \frac{Q^2xp'(Q)}{\psi^{SOC}} < 0. \tag{11}$$

Thus, at full merger $s=1$, a marginal reduction in s increases downstream producer surplus.

Next, substituting $s=0$ into (**??**) yields

$$\left.\frac{dPS^D(w(s),s)}{ds}\right|_{s=0} = \frac{Q^2p'(Q)[2x+(2-z)tp'(Q)\Gamma'(x)]}{2\psi^{SOC}}. \tag{12}$$

Here, solving $dPS^D(w(s),s)/ds|_{s=0} > 0$ for t, we have

$$t > \frac{2x}{(z-2)p'(Q)\Gamma'(x)} \equiv t^{corner}. \tag{13}$$

When $t > t^{corner}$, we have $dPS^D(w(s),s)/ds|_{s=0} > 0$ and $dPS^D(w(s),s)/ds|_{s=1} < 0$, there is no corner solution. Meanwhile, since $PS^D(w(s),s)$ is a continuous function of s, there is an interior solution $s^* \in (0,1)$ such that $PS^D(w(s),s)$ is maximized, i.e., satisfying the first-order condition $dPS^D(w(s),s)/ds = 0$.

Solving (**??**) for s yields:

$$s^* = 1 - \frac{2x}{(z-2)tp'(Q)\Gamma'(x)}. \tag{14}$$

We can easily find that s^* tends to decrease with the efficiency of the upstream investment (smaller t and $\Gamma'(x)$, larger x) and larger downstream market (smaller z and $p'(Q)$). Notably, as far as the term $2x/[(z-2)tp'(Q)\Gamma'(x)]$ in (**??**) is positive, i.e., the upstream cost-reducing investment exists ($x > 0$), then s^* is always less than 1, which suggests that merger ($s=1$) is not preferred compared with cross-holdings. This is also proved in (**??**) showing $dPS^D(w(s),s)/ds|_{s=1} < 0$.

Summarizing the above results, we obtain the following proposition.

Proposition 1 *(i) If* $t > t^{corner}$*, there exists an interior optimal cross-holding rate* $s^* \in (0, 1)$ *given by (14).*

(ii) Moreover, $s^* < 1$ *whenever upstream investment is positive* $(x > 0)$*, hence downstream firms always prefer cross-holdings to a full horizontal merger.*

(iii) If $t \leq t^{corner}$*, then* $dPS^D(w(s), s)/ds < 0$ *for all* $s \in [0, 1)$*, and the optimal is* $s^* = 0$*.*

The downstream firms face a trade-off when increasing the cross-holding rate s. On one hand, a higher s softens downstream Cournot competition, which directly raises their joint profit for any given input price w. We call this the *direct market-softening effect*. On the other hand, a higher s reduces the upstream firm's output, which weakens its incentive to invest in cost-reducing R&D and leads to a higher input price w. This *indirect strategic effect* harms downstream profits.

At $s = 1$ (full merger), the downstream market is already monopolized, so the direct market-softening effect vanishes, while the indirect strategic effect remains negative. Hence, $dPS^D/ds|_{s=1} < 0$, implying that a slight reduction in s increases downstream profit. Thus, full merger is never optimal.

At $s = 0$ (no cross-holdings), the direct market-softening effect is strong, while the magnitude of the indirect effect depends on upstream R&D efficiency. When upstream R&D is sufficiently inefficient (large t), the upstream firm invests little regardless of market conditions, so the increase in w following a rise in s is small. Hence, the direct effect dominates, yielding $dPS^D/ds|_{s=0} > 0$. When t is below the threshold t^{corner}, the indirect effect dominates, and downstream profit decreases with s from the start, leading to the corner solution $s^* = 0$.

When $t > t^{corner}$, the signs at the two boundaries ($+$ at $s = 0$, $-$ at $s = 1$) guarantee by continuity an interior maximum $s^* \in (0, 1)$.

Linear inverse demand and quadratic investment cost To illustrate the mechanism and show the range of possible optimal cross-holding rates, we now consider the linear-quadratic specification: $p(Q) = a - bQ$, $\Gamma(x) \equiv \gamma x^2/2$, and $b\gamma \geq 1/(3+s)$.[1] Then, we have $p'(Q) = -b$, $\Gamma'(x) = \gamma x$, $z = 0$, and $t = 1$. Substituting them into (**??**) and solving for s, we have:

Proposition 2 *(i) the optimal degree of cross-holdings is*

$$s_L^* = \begin{cases} 0 & \textit{if } \dfrac{1}{3+s} \leq b\gamma \leq 1, \\ 1 - \dfrac{1}{b\gamma} & \textit{if } b\gamma > 1, \end{cases}$$

where the subscript 'L' denotes the case with linear inverse demand; (ii) s_L^* increases with $b\gamma (\geq 1)$ and $\lim_{b\gamma \to \infty} s_L^* = 1$; (iii) when $s_L^* = 0$, it also maximizes total surplus; (iv) any degree of cross-holdings can be attained in equilibrium.

We depict the optimal degree of cross-holdings as in Figure 1. The horizontal axis is $b\gamma$. A larger $b\gamma$ means either a smaller market (steeper demand) or less efficient upstream R&D (higher R&D cost). In either case, the upstream firm's investment responds less to changes in downstream output, so the negative indirect effect of cross-holdings is weaker, making a higher cross-holding rate more attractive to downstream firms. In addition, from Figure 1, we find that any degree of cross-holdings can be attained as the equilibrium level, rationalizing the wide variation observed across industries.

4 Conclusion

This paper endogenies the cross-holding decision in a vertically related market with upstream R&D. While Hu et al. (2022) and Jin et al. (2024) examine the effects of exogenous cross-holdings, we show how firms choose their cross-holding rates through Nash bargaining. We find that an interior optimal cross-holding rate exists only when upstream R&D is sufficiently inefficient; otherwise, the optimal choice is no cross-holdings. Moreover, full merger is never optimal: downstream firms always prefer cross-holding to a full horizontal

[1]The last assumption is needed for the positive marginal cost for the upstream firm in equilibrium, $c - x \geq 0$.

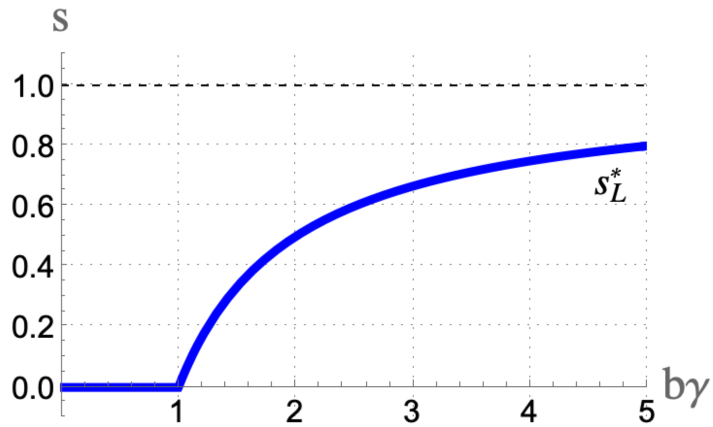

Figure 1: The optimal cross-holdings rate

merger. Additionally the optimal cross-holding rate decreases with upstream R&D efficiency and increases with downstream market size. Finally, in the linear-quadratic case, any degree of cross-holdings can arise in equilibrium, rationalizing the wide variation observed across industries.

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