Cross-Ownership and Endogenous R&D Risk in Cournot Triopoly

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Abstract

We examine how cross-ownership influences firms' endogenous R&D risk-taking in a Cournot triopoly, where two "insider" firms hold passive equity stakes in each other, and a third firm remains unaffiliated. Firms invest in stochastic R&D that lowers marginal costs and choose their risk level—measured by outcome variance—prior to quantity competition. Cross-ownership affects insiders through financial alignment and R&D spillovers, both intensifying with stronger equity links. Solving the two-stage game, we find that cross-ownership yields asymmetric, nonlinear impacts on innovation strategy. When spillover sensitivity is low, insiders undertake higher-risk R&D than the outsider; when sensitivity is high, this ranking may reverse. Increased cross-ownership always dampens the outsider's R&D risk, while insiders' risk rises with cross-holdings when spillovers are weak, but follows a U-shaped pattern when spillovers are strong. Enabling R&D collaboration does not affect the outsider, but can reduce insiders' risk-taking when spillovers are substantial. However, when spillovers are exogenous and independent of equity ties, insiders' risk increases monotonically with cross-ownership. These results identify information-sharing sensitivity as the key moderator of ownership networks' innovation risk-taking, offering implications for competition and innovation policy.

Keywords: R&D risk; cross-ownership; triopoly; non-cooperative R&D; cooperative R&D; quantity competition.

JEL Classification: D21; D43; L13

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1 Introduction

The proliferation of cross-shareholdings across advanced industries has fundamentally reshaped the interaction between competition and innovation. Firms in sectors such as semiconductors, pharmaceuticals, and renewable energy increasingly hold passive equity stakes in their rivals, creating intricate networks of partial ownership that blur the boundaries between cooperation and rivalry. In Japan, approximately 38% of listed companies maintained cross-shareholdings in 2023, a reflection of long-standing *keiretsu* structures. Similar patterns are found in South Korea's *chaebol* groups, where mutual holdings among technology leaders such as Samsung Electronics and SK Hynix have supported coordinated R&D and process innovation. In Europe, cross-holding arrangements underpinning Germany's Automotive Industry Alliance have been credited with accelerating patent development and technological diffusion. Such ownership structures, while often motivated by financial or strategic considerations, also carry profound implications for firms' willingness to engage in risky innovation.

At the core of technological progress lies the decision to undertake risky, uncertain R&D. Cross-ownership complicates this decision in subtle but important ways. On the one hand, financial alignment between firms can soften competition, reduce duplicative investments, and create implicit insurance mechanisms that encourage bold innovation. On the other hand, deeper transparency and information flows within ownership networks may erode firms' ability to appropriate the returns from successful R&D, making them more cautious. While empirical studies increasingly document how ownership structures influence innovation outcomes, theoretical understanding of how cross-shareholding affects firms' strategic R&D risk-taking—particularly in oligopolistic settings beyond the standard duopoly—remains limited. This paper fills this gap by developing a formal model that endogenizes firms' R&D risk choices under cross-ownership and information spillovers.

R&D inherently involves uncertainty arising from unpredictable technological outcomes, shifting demand, and long development lags. In markets characterized by ownership networks, this uncertainty interacts with two intertwined forces—financial interdependence and information spillovers—that pull firms' incentives in opposite directions. For insider firms within a network, mutual equity stakes can provide partial insurance against failure, lower financing constraints, and foster trust, all of which mitigate downside risk. At the same time, these very linkages can lead to knowledge leakage and imitation, diminishing the private returns to successful innovation. For outsider firms, the absence of ownership ties shields them from information spillovers but deprives them of the insurance and coordination benefits available to insiders. Outsiders may therefore behave more aggressively, undertaking bolder innovation projects to gain a competitive edge against a partially colluding network. This duality produces a conceptual tension: ownership networks may simultaneously enhance and dampen innovation risk-taking. From a welfare and policy perspective, this tension raises fundamental questions.

When do financial alignment and mutual risk-sharing promote bold innovation, and when does information leakage dominate and discourage it? How does the structure of equity ties influence the distribution of innovation risk across insiders and outsiders? Theoretical answers remain limited, particularly beyond the standard duopoly framework that dominates the existing literature.

To address these issues, this paper develops a model that endogenizes firms' R&D risk choices in a Cournot triopoly where two firms mutually hold passive equity stakes and a third remains independent. The cross-owned firms—hereafter referred to as insiders—form an ownership network through which R&D information is partially shared, while the independent firm, the outsider, competes outside the network. Within this framework, we examine how cross-ownership intensity and information-sharing sensitivity jointly determine equilibrium R&D risk-taking and how these effects differ between insiders and outsiders. The model also allows for an extension in which insider firms engage in cooperative R&D, thereby enabling an assessment of whether collaboration amplifies or dampens their propensity to pursue risky innovation.

The analytical framework proceeds in two stages. In the first stage, firms simultaneously choose the variance of their stochastic R&D outcomes, representing their endogenous level of R&D risk. In the second stage, they compete à la Cournot in quantities, taking realized cost reductions as given. Cross-ownership introduces two primary mechanisms. The first is a financial-alignment channel, through which mutual equity stakes provide partial risk sharing and align firms' profit objectives. The second is an informational channel, through which the degree of R&D spillovers rises with the strength of ownership ties. By capturing the interaction between these two mechanisms, the model explains how ownership networks can induce asymmetric and nonlinear responses in firms' innovation risk strategies, offering new theoretical insight into the nexus between cross-ownership and R&D risk-taking.

Solving the model yields several novel results. First, when the sensitivity of information sharing to ownership is low, insiders pursue higher-risk R&D projects than the outsider. In this regime, limited information leakage preserves competitive advantage while cross-ownership provides implicit financial insurance, making risky innovation more attractive. When information sensitivity is high, however, spillovers dominate: insiders' incentives for risky R&D weaken because successful innovation is easily imitated within the network. The ranking of risk propensities may then reverse, with the outsider becoming more aggressive than the insiders. Second, increasing cross-ownership consistently reduces the outsider's R&D risk but has a non-monotonic effect on insiders: at low information sensitivity, deeper equity ties encourage riskier projects; when sensitivity is high, the relationship becomes U-shaped as risk sharing eventually offsets the disincentive from information leakage. Third, allowing the insiders to cooperate in R&D leaves the outsider's strategy unchanged but can dampen insiders' risk-taking when information spillovers are strong. In contrast, when spillovers are exogenously fixed and unrelated to ownership intensity, cross-ownership monotonically raises insiders' R&D risk, underscoring information-sharing sensitivity as the key moderating mechanism.

Conceptually, our paper contributes to the literature in three ways. First, it extends research on cross-ownership beyond price and quantity competition by introducing the innovation-risk dimension as a strategic variable. Second, it connects two previously separate strands of theory—partial cross-ownership and endogenous R&D risk—to uncover how ownership networks shape innovation incentives through intertwined financial and informational channels. Third, the results highlight a novel nonlinear mechanism: equity ties can simultaneously act as risk-sharing devices and conduits for information leakage, leading to heterogeneous and sometimes counterintuitive effects on firms' willingness to innovate boldly. From a policy perspective, our analysis provides new insights into the welfare implications of overlapping ownership. While cross-holdings may enhance efficiency by facilitating knowledge exchange and reducing redundant R&D, they can also suppress high-risk innovation when spillovers are excessive, potentially dampening technological breakthroughs. Regulators evaluating partial common ownership or R&D cooperation agreements should thus account for how ownership networks influence not only market power but also firms' endogenous risk incentives.

This study relates to three strands of literature. The first examines firms' *strategic R&D risk choices* under uncertainty. Because innovation typically involves unpredictable outcomes and long time horizons, early theoretical works focused on firms' incentives to undertake risky R&D in patent races and innovation timing models (Bagwell and Staiger, 1990; Cabral, 1994; Dasgupta and Stiglitz, 1980; Ishibashi and Matsumura, 2006; Klette and De Meza, 1986; O'Donoghue, 1998). More recent studies explicitly model R&D outcomes as stochastic, using the variance of project returns to capture endogenous risk decisions. Within this framework, scholars such as Cabral (2003), Tishler (2008), Zhang et al. (2013), and Zhang (2020) analyze firms' motivations to select high-risk innovation projects in competitive environments. Extensions by Xing (2017), Li and Xu (2026, forthcoming), and Xing and Lee (2025b) compare risk-taking behavior under cooperative and non-cooperative R&D, while others explore how institutional features—such as network externalities (Xing, 2014; Zhang et al., 2024), privatization (Lee, 2017; Xing, 2019), corporate social responsibility (Lee and Cho, 2020; Xing and Lee, 2025b), environmental policy (Xing et al., 2021; Zhang et al., 2024) and managerial delegation Xing and Lee (2026b, forthcoming)—shape firms' optimal R&D risk. This line of inquiry shares conceptual commonalities with the literature on endogenous R&D networks, which examines how the architecture of firm connections—whether driven by cost-reduction or strategic considerations—shapes innovation incentives. For instance, Kim et al. (2025) explore how network structures interact with environmental corporate social responsibility to determine firms' R&D effort, highlighting the asymmetric behavior that often emerges between firms within a connected network and those remaining unconnected. While our framework focuses on passive equity stakes rather than explicit link formation, it similarly identifies how the position of a firm—either as a networked 'insider' or an independent 'outsider'—fundamentally alters its strategic response to uncertainty. By linking R&D risk decisions with these ownership-based networks, we provide a complementary perspective on how structural asymmetries in the market moderate incentives for risky innovation. Unlike prior studies that treat firms as independent competitors, we specifically model how cross-ownership ties affect the endogenous selection of R&D risk, thereby introducing a distinct ownership-based mechanism that governs the propensity for technological breakthroughs.

A second body of research investigates how *cross-ownership affects firms' R&D investment strategies*. Cross-shareholding creates financial linkages between rivals and can influence innovation through both competition-softening and spillover effects. In models without R&D spillovers, Shelegia and Spiegel (2024) show that partial cross-ownership may benefit consumers by moderating price competition and thereby stimulating innovation, while Xing et al. (2024) and Cheng et al. (2024) find that private cross-ownership induces semi-public firms—but discourages private firms—to invest more in R&D in mixed oligopolies. When spillovers are explicitly considered, López and Vives (2019) demonstrate that overlapping ownership raises R&D for large spillovers but reduces it for small ones. Similarly, Chen et al. (2024) emphasize that cross-ownership among public or mixed enterprises encourages partial knowledge sharing and intentionally increases spillover intensity, whereas Zhang et al. (2025) show that endogenizing knowledge disclosure leads both semi-public and private firms to expand their R&D efforts as cross-holdings deepen. More recently, the literature has further nuanced these relationships by considering asymmetry, competing strategic effects, and policy interventions. Shastry and Sinha (2025) examine a Cournot duopoly with partial cross-ownership where only one firm invests in cost-reducing R&D, finding that the impact of equity ties is critically dependent on the R&D investment's efficiency parameter. Chen et al. (2025) identify a dual mechanism in R&D decisions, showing that the outcome of cross-ownership hinges on the trade-off between a "prospect-improving effect" and a "competition-softening effect." Furthermore, Xing and Lee (2026a, forthcoming) extend the analysis to policy interactions, demonstrating that the presence of research subsidies can alter—and sometimes reverse—the effects of cross-ownership on cooperative and non-cooperative R&D compared to non-subsidized scenarios. In contrast to these works, our paper focuses on the *risk composition* rather than the *level* of R&D investment. By incorporating endogenous R&D variance as a strategic choice, we shift the analysis from how cross-ownership influences investment magnitude to how it shapes firms' willingness to pursue risky, uncertain innovations through intertwined financial and informational channels.

Finally, a growing literature explores the interaction between *cross-ownership and R&D risk-taking*. Xing and Tan (2023) and Li et al. (2025) show in duopoly models that partial passive ownership holdings (PPOs) increase firms' willingness to engage in risky R&D, whether targeting cost reduction or environmental innovation. Li et al. (2026) further find that cross-ownership raises optimal R&D risk under both cooperative and non-cooperative regimes, with cooperation amplifying the effect. However, these studies remain limited to duopolies and do not account for networked ownership structures or endogenous spillover mechanisms. Our study departs from this literature by examining a *triopoly network* in which two insider firms mutually hold equity stakes and partially share R&D information, while an outsider remains independent. By endogenizing the sensitivity of information sharing to ownership intensity, this framework captures how cross-ownership simultaneously alters financial alignment and informational exposure, offering a more comprehensive view of how ownership networks influence firms' strategic R&D risk choices.

The remainder of the paper is organized as follows. Section 2 presents the baseline Cournot triopoly model, introducing the structure of cross-ownership, the specification of R&D costs, and the sequence of strategic decisions. Section 3 derives the equilibrium R&D risk choices and analyzes how cross-ownership and information sensitivity jointly determine insiders' and the outsider's risk-taking behavior. Section 4 extends the framework to examine cooperative R&D among insiders and the case where spillovers are exogenous, highlighting the robustness of our main findings. Section 5 discusses additional implications and concludes. Proofs and derivations are collected in the Appendix.

2 Baseline Model Setup

We examine a Cournot triopoly in which three firms, indexed by $i \in \{0, 1, 2\}$, produce a homogeneous good. The inverse demand function is

$$p = a - Q,$$

where $a > 0$ represents market size, $q_i \geq 0$ is firm i's output, and

$$Q \equiv \sum_{i=0}^{2} q_i$$

denotes total industry output.

Firms 1 and 2 each hold a symmetric, passive equity stake $k \in (0, \frac{1}{2})$ in one another, without control rights. Firm 0 holds no shares in the others, nor do firms 1 and 2 hold any stake in firm 0. Thus, the shareholding network consists of firms 1 and 2 as *intra-network* firms (i.e., insiders), while firm 0 is an *out-of-network* firm (i.e., outsider).

Each firm's marginal cost depends on its R&D investment. Specifically, the marginal costs are:

$$c_0 = c - x_0, \quad c_1 = c - x_1 - bx_2, \quad c_2 = c - x_2 - bx_1,$$

where x_i denotes firm i's R&D effort, c is the baseline marginal cost, and $b = 2fk$ reflects the degree of R&D information sharing between insiders. The parameter $f \in (0, 1)$ captures the sensitivity or efficiency of information sharing with respect to cross-ownership intensity. Economically, f represents the degree of friction or permeability in the information transmission channel created by equity ties. A higher f implies that cross-shareholding grants insiders significant access to each other's proprietary knowledge—potentially facilitated by mechanisms such as board representation, personnel exchange, or joint technical committees—thereby making spillovers highly sensitive to ownership levels. Conversely, a lower f suggests that despite mutual equity stakes, information leakage is dampened by factors such as strict corporate secrecy policies, high technological complexity, or regulatory barriers that maintain operational separation. Note that R&D spillovers occur only among insider firms; the outsider receives no such benefit.

The profit function of firm i is given by:

$$\pi_i = (p - c_i)q_i - I(\mu_i, \sigma_i), \tag{1}$$

where $I(\mu_i, \sigma_i)$ denotes the firm's R&D cost function. The R&D effort x_i is a random variable distributed according to $F[x_i; \mu_i, \sigma_i]$, with mean μ_i and variance σ_i; that is, $\mathbb{E}(x_i) = \mu_i$ and $\text{Var}(x_i) = \sigma_i$. We assume $x_i \geq 0$ and that the cost function is increasing in the mean, i.e., $\partial I(\mu_i, \sigma_i)/\partial \mu_i > 0$.

Following Xing et al. (2021), the R&D cost function further satisfies two properties: (i) it is strictly convex in variance,

$$\frac{\partial^2 I(\mu_i, \sigma_i)}{\partial \sigma_i^2} > 0,$$

and (ii) the cost becomes unbounded as variance grows,

$$\lim_{\sigma_i \to +\infty} I(\mu_i, \sigma_i) = \infty.$$

Here, variance σ_i captures the riskiness of R&D investments.

We also impose the following assumptions: (i) firms are risk-neutral; (ii) R&D efforts x_0, x_1, x_2 are mutually independent[1]; and (iii) the distribution of each x_i is common knowledge.

Firms aim to maximize their total profits. Their objective functions are:

$$V_0 = \pi_0, \tag{2}$$

$$V_i = (1 - k)\pi_i + k\pi_j, \; i, j = 1, 2, \; i \neq j. \tag{3}$$

[1]This assumption is made to simplify the theoretical analysis. One might consider a scenario where R&D outcomes are correlated due to common technological uncertainties, such as $Cov(x_i, x_j) = \rho > 0$. Our supplementary analysis indicates that while correlation affects the absolute magnitude of expected profits, it does not alter the signs of the comparative statics or the main qualitative conclusions derived in this paper. A similar robustness result regarding correlated R&D outcomes is also discussed in Xing and Tan (2023).

Social welfare is defined as the sum of consumer surplus (i.e., CS) and the profits of firms, which is given as follows:

$$SW = CS + \sum_{i=0}^{2} \pi_i = aQ - \frac{1}{2}Q^2 - \sum_{i=0}^{2}[c_i q_i + I(\sigma_i)] \tag{4}$$

where $CS = \frac{1}{2}Q^2$.

The game proceeds in two stages. In the first stage, firms simultaneously and non-cooperatively select their R&D risk levels, σ_i, prior to the realization of R&D outcomes, x_i. In the second stage, after observing the realized R&D outcomes, firms simultaneously choose their output, q_i.

3 Equilibrium R&D Risk in the Baseline Model

We solve the model using backward induction. In the second stage, firms non-cooperatively choose their output levels. Given realized R&D outcomes x_1 and x_2, each firm maximizes its objective function with respect to its own output. The first-order conditions are:

$$\frac{\partial V_0}{\partial q_0} = a - (c - x_0) - q_0 - Q = 0, \tag{5}$$

$$\frac{\partial V_i}{\partial q_i} = (1-k)[a - (c - x_i - 2fkx_j) - q_i - Q] = 0, \quad i, j \in \{1, 2\},\ i \neq j. \tag{6}$$

Solving equations (5) and (6) yields the Cournot-Nash equilibrium quantities:

$$q_0 = \frac{a - (3-2k)(c - x_0) + (1-k)[2c - (1+2fk)(x_1 + x_2)]}{2(2-k)}, \tag{7}$$

$$q_i = \frac{(1-k)\left\{(1-2k)(a + c - x_0) - 3(1-k)(c - x_i - 2fkx_j) + (1+k)(c - x_j - 2fkx_i)\right\}}{2(2 - 5k + 2k^2)}, \tag{8}$$

$i, j \in \{1, 2\},\ i \neq j.$

The second-order conditions for profit maximization are satisfied since:

$$\frac{\partial^2 \pi_0}{\partial q_0^2} = -2 < 0 \quad \text{and} \quad \frac{\partial^2 \pi_i}{\partial q_i^2} = -2(1-k) < 0.$$

In the first stage, firms choose among a set of R&D projects with identical expected outcomes but different levels of risk. That is, μ_i is treated as constant, and for simplicity, we assume $\mu_1 = \mu_2 = \mu$.[2] Since μ_i is a constant and symmetric across firms, the specific value of μ_i does

[2]The results remain qualitatively unchanged if $\mu_1 \neq \mu_2$, provided both are fixed.

not affect the equilibrium R&D risk levels. Thus, we suppress μ_i in the R&D cost function notation and directly express it as the form $I(\sigma_i)$ in the subsequent analysis. This setup is equivalent to firms choosing the variance σ_i of their R&D outcomes, similar to the settings in Tishler (2008), Zhang et al. (2013), and Xing (2014, 2017).

Substituting equilibrium quantities (7) and (8) into (1)–(3) and taking expectations, we obtain the following expressions for expected profits:

$$E(V_0) = \frac{[a-c+(1-4fk(1-k))\mu]^2 + (3-2k)^2\sigma_0 + (1-k)^2(1+2fk)^2(\sigma_1+\sigma_2)}{4(2-k)^2} - I(\sigma_0), \tag{9}$$

$$E(V_i) = \frac{(1-k)}{4(2-k)^2(1-2k)} \left\{ \begin{aligned} &(1-2k)[a-c+(1+4fk)\mu]^2 + (1-2k)\sigma_0 \\ &+ \big[4f^2k^2(4k^3-13k^2+8k+1) + 2fk(-2k^2+4k-6) \\ &\quad -4k^3+15k^2-20k+9\big]\,\sigma_i \\ &+ \big[4f^2k^2(-4k^3+15k^2-20k+9) + 2fk(-2k^2+4k-6) \\ &\quad +4k^3-13k^2+8k+1\big]\,\sigma_j \end{aligned} \right\} \tag{10}$$
$$- (1-k)I(\sigma_i) - kI(\sigma_j), \quad i,j \in \{1,2\},\ i \neq j.$$

As R&D outcomes are uncertain in the first stage, each firm selects the risk level σ_i that maximizes its expected profit. The first-order conditions are:

$$\frac{\partial E(V_0)}{\partial \sigma_0} = \frac{(3-2k)^2}{4(2-k)^2} - \frac{\partial I(\sigma_0)}{\partial \sigma_0} = 0, \tag{11}$$

$$\frac{\partial E(V_i)}{\partial \sigma_i} = \frac{(1-k)\left[4k^2(4k^3-13k^2+8k+1)f^2 + 2k(-2k^2+4k-6)f - 4k^3+15k^2-20k+9\right]}{4(2-k)^2(1-2k)}$$
$$- (1-k)\frac{\partial I(\sigma_i)}{\partial \sigma_i} = 0, \quad i = 1,2. \tag{12}$$

Using (11) and (12), the first-order condition for firm i's risk choice does not depend on the rival's variance term σ_j. This implies that the decisions are separable. That is, even under incomplete information about the competitor's R&D variance, the optimal decision remains unaffected.[3]

Given that μ_i is constant and $\mu_1 = \mu_2 = \mu$, we define:

$$h(\sigma_i) \equiv \frac{\partial I(\sigma_i)}{\partial \sigma_i}, \tag{13}$$

which represents the marginal cost of R&D risk for firm i. Using equations (11), (12), and (13), the equilibrium R&D risk levels satisfy:

$$\frac{(3-2k)^2}{4(2-k)^2} = h(\sigma_0^n), \tag{14}$$

$$\frac{4k^2(4k^3 - 13k^2 + 8k + 1)f^2 + 2k(-2k^2 + 4k - 6)f - 4k^3 + 15k^2 - 20k + 9}{4(2-k)^2(1-2k)} = h(\sigma_i^n), \quad i = 1, 2. \tag{15}$$

Here, σ_i^n denotes the equilibrium R&D risk level for firm i. Note that insiders share the same equilibrium expression due to symmetry.

3.1 Risk-Taking Differences Between Insider and Outsider Firms

Comparing the equilibrium R&D risk levels of the insider firms and the outsider, we derive the following result:

Proposition 1. *(i) When f is sufficiently small, $\sigma_0^n < \sigma_i^n$ for $i = 1, 2$.*
(ii) When f is sufficiently large, there exists a threshold level of cross-ownership, denoted $k_1(f)$, such that $\sigma_0^n > \sigma_i^n$ if $k < k_1(f)$, and $\sigma_0^n < \sigma_i^n$ if $k > k_1(f)$.

As illustrated in Figure 3.1, Proposition 1 indicates that the relative R&D risk level between insiders and the outsider hinges on two key parameters: the information-sharing sensitivity (f) and the cross-ownership intensity (k). When the information-sharing sensitivity to cross-ownership is weak (small f), insiders tend to undertake high-risk, high-reward R&D projects than the outsider. In contrast, when f is large, the direction of this relationship depends on the cross-ownership level: if the shareholding level k is low (high), the insiders (outsider) will be less inclined to engage in risky R&D.

[3]While our analysis focuses on a triopoly, the separability of the first-order conditions suggests that the qualitative results are robust to a larger number of firms. As seen in (11) and (12), the marginal benefit of R&D risk in the first stage is independent of the rival's variance (σ_j) and specific output levels; it is determined by the ownership intensity k and information-sharing sensitivity f. In an n-firm expansion, as long as the ownership network remains concentrated among "insider" firms, the fundamental trade-off between financial risk-sharing and informational leakage would continue to drive the asymmetric risk-taking behavior between insiders and outsiders.

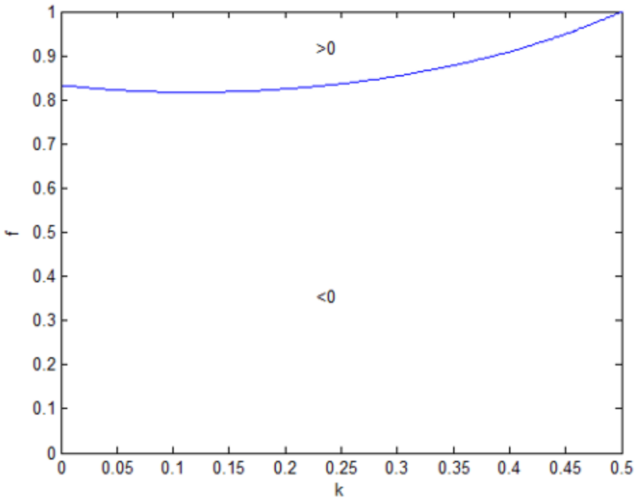

Figure 3.1: Sign of $\sigma_0^n - \sigma_i^n$.

When the information-sharing sensitivity f is relatively low, two mechanisms incentivize insiders to undertake riskier R&D projects compared to the outsider. First, a low f implies limited R&D information leakage between insiders. As a result, the risk of proprietary knowledge erosion is minimal, allowing the innovator to internalize the majority of the returns. This preserves the proprietary competitive advantage gained from successful high-risk, high-reward R&D investments, thereby increasing the private returns to such projects. Second, cross-ownership k plays a risk-sharing role. When insiders invest in high-risk R&D and the project fails, the financial consequences are partially absorbed through their mutual equity stakes. This dilution of downside risk effectively creates an internal insurance mechanism, which the outsider—lacking any cross-holdings—cannot access. Taken together, these factors create a favorable payoff structure for insiders: the upside from successful R&D is protected due to weak spillovers (low f), while the downside from failure is mitigated through ownership-based risk-sharing (positive k). This dual benefit increases insiders' willingness to engage in high-risk R&D relative to the outsider.

When f is large, however, heightened R&D transparency among insiders can undermine the competitive advantage of successful innovators. Extensive information leakage allows equity-linked rivals to partially access technological breakthroughs. Even if the effective spillover $b = 2fk$ is small due to low ownership k, the high sensitivity f implies that the marginal rate of leakage is significant relative to the financial integration. Consequently, the primary driver for reduced risk-taking in this regime is not an intent to free-ride—since the inbound benefit is low—but rather limited appropriability. The innovating firm anticipates that the exclusivity of its R&D outcome is compromised, which dilutes the incentive to pursue high-variance projects. This weakened incentive due to appropriability concerns diminishes the expected profitability of risky R&D investment within the network, leading insiders to behave more cautiously than the outsider.

The role of cross-ownership (k) becomes critical under this circumstance. When k is small, the extent of financial interdependence among insiders is limited, meaning that the benefits of risk-sharing are insufficient to offset the adverse effect of high information transparency (f). As a result, insiders face both higher effective spillover losses and limited insurance against R&D failure, making them less inclined than the outsider to engage in risky innovation. Conversely, when k is sufficiently large, the cross-ownership among insiders provides stronger mutual insurance, effectively mitigating the downside losses associated with failed R&D. The enhanced risk-sharing benefit can then outweigh the profit-diluting effect of large f, restoring insiders' incentives to pursue high-risk projects. Hence, under high information sensitivity, whether insiders or the outsider are more risk-prone depends critically on the strength of cross-ownership ties.

3.2 The Impact of Cross-Ownership and Information-Sharing Sensitivity on R&D Risk

We now turn to the comparative statics of the equilibrium R&D risk levels with respect to cross-ownership intensity k. The following proposition summarizes our results:

Proposition 2. *(i) The outsider's equilibrium R&D risk decreases with cross-ownership:* $\frac{\partial \sigma_0^n}{\partial k} < 0$.
(ii) For insider firms, when f is small, cross-ownership increases their R&D risk: $\frac{\partial \sigma_i^n}{\partial k} > 0$*, for* $i = 1, 2$.
(iii) When f is large, the relationship is non-monotonic: $\frac{\partial \sigma_i^n}{\partial k} < 0$ *if* $k < k_2(f)$*, and* $\frac{\partial \sigma_i^n}{\partial k} > 0$ *if* $k > k_2(f)$*, where* $k_2(f)$ *is a threshold level of cross-ownership determined by the sensitivity of R&D information sharing.*

Proposition 2 provides two key insights. First, cross-ownership among insiders has a dampening effect on the outsider's R&D incentives. Second, for insiders themselves, the relationship between equity linkages and innovation risk-taking depends critically on the sensitivity of information sharing f. When f is low, increasing cross-ownership raises insiders' R&D risk levels; however, when f is high, the relationship becomes non-monotonic: insiders reduce R&D risk when k is small, but increase it once k exceeds a threshold $k_2(f)$.

As cross-ownership (k) rises, insiders share R&D risks more effectively through their equity ties, forming an implicit coalition that dilutes R&D losses. The outsider, by contrast, faces its R&D risk in isolation and cannot offset failures through similar financial linkages. Competing against a coalition with built-in risk diversification and strategic synergy places the outsider at a disadvantage: its effective risk exposure is higher, while the expected payoff from risky innovation is lower. Hence, the outsider optimally shifts toward less risky R&D as k increases.

As illustrated in Figure 3.2, the influence of cross-ownership on insiders' R&D risk-taking reflects a balance between financial alignment and information leakage. When the sensitivity of information sharing f is low, limited leakage allows each insider to retain most of the benefits from its own innovation. In this case, stronger equity ties (k) deepen mutual financial alignment and dilute potential losses, encouraging insiders to pursue riskier, high-return R&D projects. When f is large, however, equity linkages transmit substantial R&D information across insiders. Greater transparency erodes the exclusivity of innovation outcomes and weakens private incentives for risky investment. At low levels of k, this information leakage dominates, leading insiders to invest more cautiously. As k increases beyond a threshold $k_2(f)$, the benefits of deeper financial interdependence and coordinated strategy begin to outweigh the costs of excessive transparency. Beyond this point, insiders' willingness to bear R&D risk rises again, producing the observed non-monotonic (U-shaped) relationship between cross-ownership and innovation risk.

It is worth noting that this non-monotonic result contrasts with the findings in related duopoly studies, such as Xing and Tan (2023) and Li et al. (2025b), which typically document a monotonic increase in R&D risk-taking as cross-ownership rises. The divergence stems from the different market structures considered. In a pure duopoly, cross-ownership primarily softens mutual competition and aligns incentives without the threat of external business-stealing. In our triopoly framework, however, the outsider exerts continuous competitive pressure. Consequently, while high information spillovers initially dampen insiders' risk incentives at low ownership levels (the downward slope), the necessity to maintain a competitive edge against the aggressive outsider compels insiders to leverage the risk-sharing benefits of cross-ownership once equity ties are sufficiently strong, thereby driving the risk levels back up (the upward slope). This "external discipline" effect imposed by the outsider is a unique feature of the network setting that is absent in standard duopoly models.

4 Extensions and Robustness Analysis

4.1 R&D Cooperation Among Insider Firms

In contrast to the baseline model where the insider firms conduct R&D independently, this section considers the case in which firms 1 and 2 engage in cooperative R&D. During the R&D stage, each insider maximizes the joint expected profit of the network, $E(V_1) + E(V_2)$, when choosing its optimal R&D risk level. All other assumptions remain identical to those in the basic model. The second-stage Cournot equilibrium outputs are still given by equations (7) and (8), and the corresponding expected values of V_0 and V_i are those in equations (9) and (10), respectively. In the first stage, firms determine their optimal R&D risk levels, leading to the following first-order conditions:

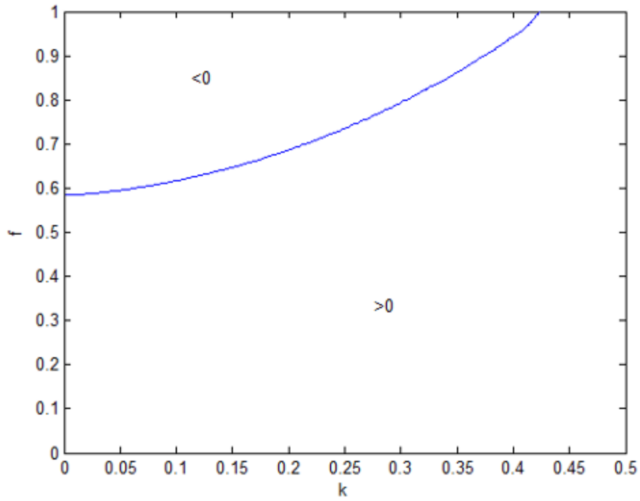

Figure 3.2: Sign of $\frac{\partial \sigma_i^n}{\partial k}$.

$$\frac{\partial E(V_0)}{\partial \sigma_0} = \frac{(3-2k)^2}{4(2-k)^2} - \frac{\partial I(\sigma_0)}{\partial \sigma_0} = 0, \tag{16}$$

$$\frac{\partial (E(V_1)+E(V_2))}{\partial \sigma_i} = \frac{(1-k)\left[(k^2-6k+5)(4k^2f^2+1)+4k(-k^2+2k-3)f\right]}{2(2-k)^2(1-2k)} - \frac{\partial I(\sigma_i)}{\partial \sigma_i}$$
$$= 0, \qquad i = 1, 2. \tag{17}$$

Using equations (16), (17), and (13), we obtain:

$$\frac{(3-2k)^2}{4(2-k)^2} = h(\sigma_0^y), \tag{18}$$

$$\frac{(1-k)\left[(k^2-6k+5)(4k^2f^2+1)+4k(-k^2+2k-3)f\right]}{2(2-k)^2(1-2k)} = h(\sigma_i^y), \tag{19}$$

where σ_i^y denotes the equilibrium R&D risk of insider firm i under cooperative R&D.

Comparing the equilibrium R&D risk levels of insiders and the outsider under cooperative R&D, we obtain the following result.

Proposition 3. *(i) When the sensitivity of information sharing to cross-ownership (f) is low, $\sigma_0^y < \sigma_i^y$, for $i = 1, 2$.*

(ii) When f is high, there exist two threshold levels of cross-ownership, denoted $k_3(f)$ and $k_4(f)$. If the shareholding level k lies between these two thresholds, $\sigma_0^y > \sigma_i^y$. When k is either below $k_3(f)$ or above $k_4(f)$, $\sigma_0^y < \sigma_i^y$.

As illustrated in Figure 4.1, the results of Proposition 3 are broadly consistent with those of Proposition 1. However, under R&D cooperation, an additional case may emerge: when f is high but k remains relatively small, insiders can still exhibit higher R&D risk than the outsider. This reversal arises from the alignment of objectives within the insider network induced by cooperative R&D. Through collaboration, insiders form a community of shared interests and shift from maximizing individual profits to maximizing joint network value. This goal convergence fundamentally modifies the role of information sharing: transparency that would otherwise dilute innovation incentives in the non-cooperative case is now partially neutralized by shared objectives. Consequently, even when information sensitivity is high and cross-ownership is low, insiders may retain stronger incentives for high-risk innovation than the outsider.

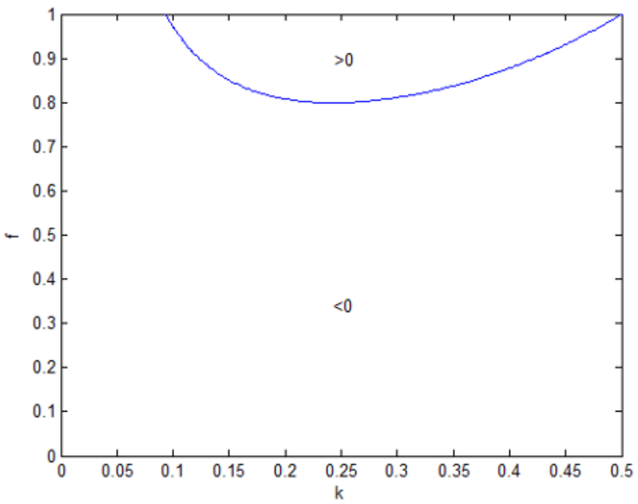

Figure 4.1: Sign of $\sigma_0^y - \sigma_i^y$.

4.1.1 Comparative Statics under Cooperation

We next perform comparative statics with respect to k and obtain the following results.

Proposition 4. *(i) The outsider's equilibrium R&D risk decreases with cross-ownership:* $\frac{\partial \sigma_0^y}{\partial k} < 0$.

(ii) For insiders, when f is low, $\frac{\partial \sigma_i^y}{\partial k} > 0$*, for $i = 1, 2$, an increase in cross-ownership k raises their equilibrium R&D risk.*

(iii) When f is large, the relationship between cross-ownership and insiders' R&D risk becomes non-monotonic. Specifically, there exists a threshold level $k_5(f)$, such that $\frac{\partial \sigma_i^y}{\partial k} < 0$ *when $k < k_5(f)$, but* $\frac{\partial \sigma_i^y}{\partial k} > 0$ *when $k > k_5(f)$.*

The comparative statics summarized in Proposition 4 are broadly consistent with those in Proposition 2, confirming that the main insights of the baseline model remain valid when insiders cooperate in R&D. Cross-ownership continues to reduce the outsider's incentive to undertake risky innovation, while insiders' responses to higher equity linkage depend on how sensitively information sharing reacts to cross-ownership. When f is low, stronger financial interdependence encourages insiders to take on more R&D risk. In contrast, when f is high, information spillovers initially discourage riskier investments; yet once k passes the threshold $k_5(f)$, the benefits of risk sharing and strategic coordination dominate, leading insiders to raise their R&D risk again.

As shown in Figure 4.2, the cooperative case expands the parameter region in which insiders' optimal R&D risk levels decline with increasing cross-ownership. This pattern indicates that R&D cooperation amplifies the suppressing effect of cross-ownership on insiders' innovation incentives, particularly when information spillovers are strong. By internalizing each other's payoffs, cooperation reduces the intensity of innovation competition between insiders. As a result, the strategic motivation to undertake high-risk R&D projects diminishes relative to the non-cooperative benchmark.

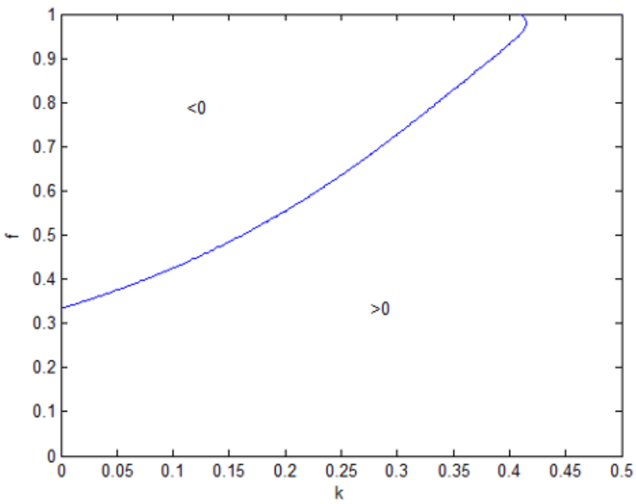

Figure 4.2: Sign of $\frac{\partial \sigma_i^y}{\partial k}$.

4.1.2 Cooperation vs. Non-Cooperation: Risk Incentives of Insiders

We compare the R&D risk decisions under cooperative and non-cooperative arrangements between the insider firms. The following proposition summarizes the key findings:

Proposition 5. *(i)* $\sigma_0^y = \sigma_0^n$*;*
(ii) When f *is small,* $\sigma_i^y > \sigma_i^n$ *for* $i = 1, 2$*;*
(iii) When f *is large,* $\sigma_i^y > \sigma_i^n$ *if* $k < k_6(f)$*, and* $\sigma_i^y < \sigma_i^n$ *if* $k > k_6(f)$*, except for a narrow region where both* f *and* k *are sufficiently large.*

As illustrated in Figure 4.3, Proposition 5 shows that R&D cooperation among insiders leaves the outsider's R&D risk decision unchanged, but substantially modifies the risk-taking incentives of insider firms. When the sensitivity of R&D information sharing to cross-ownership f is low, cooperation enhances the insiders' willingness to undertake higher R&D risk relative to the non-cooperative benchmark. Conversely, when f is high, the effect of cooperation becomes non-monotonic: depending on the level of cross-ownership k, collaboration may either stimulate or dampen risk-taking. This contrasts with earlier duopoly results (e.g., Xing and Tan, 2023; Li et al., 2025b) that predict uniformly higher R&D risk under cooperation. The divergence arises because our triopoly framework explicitly incorporates (i) an external competitor and (ii) an endogenous linkage between cross-ownership and R&D information spillovers. These two features jointly generate richer strategic interactions and a more nuanced equilibrium response of risk-taking incentives.

It is important to address the strategic role of the outsider firm. Although Proposition 5(i) indicates that the outsider's equilibrium risk level remains unchanged ($\sigma_0^y = \sigma_0^n$) regardless of whether insiders cooperate, this "neutrality" regarding the coordination regime should not be mistaken for strategic irrelevance. The outsider exerts a fundamental structural discipline on the market. As established in Proposition 2, the outsider's risk choice is strictly decreasing in the insiders' cross-ownership level, demonstrating a strong strategic response to the network structure itself. The invariance in Proposition 5 stems from the specific property of the Cournot-Nash equilibrium in the first stage, where the strategic effects of insiders' coordination on the outsider's marginal benefit of risk cancel out. However, the presence of the outsider is precisely what enables the comparative analysis in Proposition 1 and 3, allowing us to identify the conditions under which network insiders become more or less aggressive than an independent rival—a relative ranking insight that is structurally impossible to derive in a standard duopoly model.

Under collaborative R&D, insiders coordinate their innovation strategies to maximize joint expected profits, fully internalizing within-network spillovers that would otherwise lead to strategic externalities under non-cooperative behavior. This transforms cross-shareholding from partial profit alignment into a mechanism that jointly internalizes information flows and coordinates portfolio risk.

When f is small, collaboration strengthens insiders' collective willingness to pursue riskier innovation. Because information leakage is minor, the alignment of objectives mainly enhances mutual risk-sharing and reduces duplication of R&D investments, which in turn raises the expected marginal return from high-risk projects. Hence, in this regime, cooperation amplifies insiders' incentives for risk-taking relative to the non-cooperative benchmark ($\sigma_i^y > \sigma_i^n$).

When f is high, cooperation has a disciplining force: greater transparency erodes insiders' ability to appropriate innovation rents, so internalizing large spillovers pushes the coalition toward risk moderation, thereby weakening the marginal benefit from risk-taking. In most of this region, cooperative insiders may optimally choose lower R&D risk by avoiding redundant investments and optimizing resource allocation. However, when both f and k are sufficiently large, the balance flips again. Strong cross-ownership delivers powerful downside insurance and near-complete surplus pooling, so the coalition can recoup a large share of the upside created by variance while cushioning failures. Strong equity links also eliminate intra-network business-stealing, thereby increasing the joint marginal returns from successful R&D. In this narrow high-f, high-k region, the benefits from risk-sharing and coordination can outweigh the appropriation losses from spillovers, leading cooperative insiders to undertake higher R&D risk than in the non-cooperative case—that is, $\sigma_i^y > \sigma_i^n$.

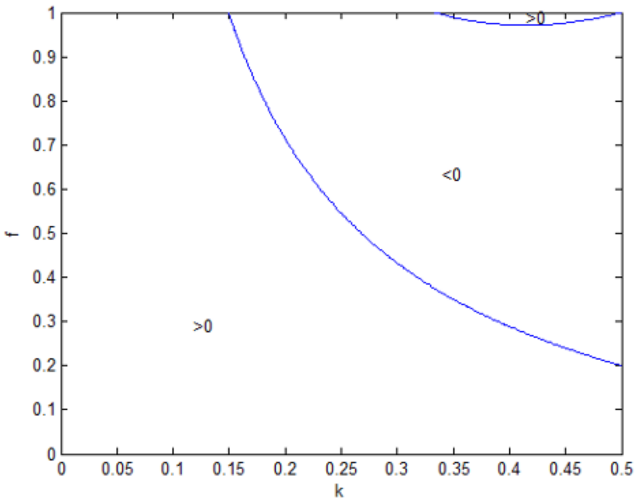

Figure 4.3: Sign of $\sigma_i^y - \sigma_i^n$.

4.2 Exogenous Spillovers: Decoupling Information Sharing from Ownership

Some related studies, such as Xing and Tan (2023) and Li et al. (2025), assume that the R&D spillover intensity b is exogenous and does not depend on the level of cross-ownership k. In this section, we consider this alternative specification. Following a procedure similar to that used in the baseline model, we derive the equilibrium R&D risk levels, which satisfy the following conditions:

$$\frac{(3-2k)^2}{4(2-k)^2} = h(\sigma_0^n), \tag{20}$$

$$\frac{(4k^3-13k^2+8k+1)b^2+(-2k^2+4k-6)b-4k^3+15k^2-20k+9}{4(2-k)^2(1-2k)} = h(\sigma_i^n). \tag{21}$$

Here, σ_i^n denotes the equilibrium R&D risk level of firm i. Equation (20) corresponds to the outsider, while equation (21) applies to the insiders ($i = 1, 2$).

Comparing the equilibrium R&D risk levels of firms inside and outside the ownership network, we obtain the following result:

Proposition 6. *(i) When* $b = 0$, $\sigma_0^n < \sigma_i^n$ *for* $i = 1, 2$;
(ii) When $0 < b < 1$, $\sigma_0^n > \sigma_i^n$ *if* $k < k_1(b)$, *and* $\sigma_0^n < \sigma_i^n$ *if* $k > k_1(b)$;
(iii) When $b = 1$, $\sigma_0^n > \sigma_i^n$ *for* $i = 1, 2$.

As illustrated in Figure 4.4, the relative R&D risk levels of insider and outsider firms depend on both the extent of R&D information sharing within the network (captured by b) and the degree of cross-ownership k.

When there is no R&D information sharing among insiders ($b = 0$), insiders tend to take on more R&D risk than the outsider. This is because insiders can share financial risks via equity ties, while maintaining the full benefit of R&D exclusivity. In contrast, when information sharing is complete ($b = 1$), the outsider is more inclined to engage in high-risk R&D than insiders. In this case, full information transparency dilutes insiders' ability to appropriate innovation rents, which weakens their incentive to invest in high-risk projects.

When information sharing is partial ($0 < b < 1$), the comparison depends on the level of cross-ownership. If k is low, insiders cannot sufficiently diversify the downside risks, making them more cautious than the outsider. If k is high, however, strong equity ties provide enough risk-sharing to offset the appropriation losses from spillovers, leading insiders to choose higher R&D risk than the outsider.

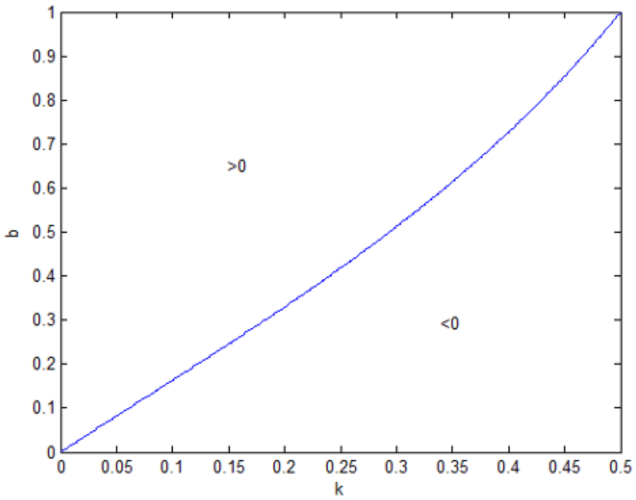

Figure 4.4: Sign of $\sigma_0^n - \sigma_i^n$.

4.2.1 Comparative Statics with Exogenous Spillovers

We next conduct a comparative statics analysis on the effect of cross-ownership k on the optimal R&D risk levels when the R&D spillover intensity b is exogenous (i.e., independent of k). The results are summarized below:

Proposition 7. *(i)* $\frac{\partial \sigma_0^n}{\partial k} < 0$*;*
(ii) $\frac{\partial \sigma_i^n}{\partial k} > 0$*, for* $i = 1, 2$*.*

Proposition 7(i) is consistent with the result in Proposition 2(i), indicating that cross-ownership among insider firms consistently exerts a suppressing effect on the R&D risk-taking behavior of the outsider, regardless of whether the degree of information sharing is endogenously linked to cross-holdings. This reflects the strategic disadvantage the outsider faces as insider coordination intensifies. In Proposition 2(iii), the relationship between σ_i^n and k could be non-monotonic, whereas here, when the R&D information-sharing intensity b is independent of k, we find $\frac{\partial \sigma_i^n}{\partial k} > 0$ for all $k \in (0, \frac{1}{2})$. This implies that cross shareholding always promotes higher R&D risk-taking among insider firms once information-sharing intensity is decoupled from equity ties. This highlights the crucial role of assuming endogenous spillovers when analyzing the full effect of cross-ownership structures on innovation strategies.

The underlying intuition is straightforward. When b is fixed, an increase in the cross shareholding level strengthens only the financial interdependence among insiders without altering the degree of information exchange. As k rises, the risk-sharing effect of equity ties becomes stronger, while the information-suppression effect remains constant. Consequently, insiders face reduced downside exposure to failed R&D outcomes but unchanged informational leakage, making high-risk projects more attractive. Therefore, when R&D information sharing does not depend on cross shareholding, deeper equity linkages unambiguously increase the insiders' incentives to undertake riskier innovation.

4.3 Social Optimum

This section considers the (second-best) socially optimal R&D risk that maximizes expected social welfare and compares private incentives with social incentives for R&D risk. Substituting equilibrium quantities (7) and (8) into the social welfare function (4) and calculating the expectation, we obtain expected social welfare:

$$E(SW) = \frac{1}{8(2-k)^2(1-2k)}\Bigg\{(1-2k)\Big[2[a-c+(1-4fk(1-k))\mu]^2 + 4(1-k)[a-c+(1+4fk)\mu]^2 + (3-2k)^2(a-c+\mu)^2\Big] + (1-2k)(8k^2-28k+23)\sigma_0 + (1-k)\Big[4f^2k^2(10k^2-33k+23) + 2fk(4k^2-2k-18) + 10k^2-33k+23\Big](\sigma_1+\sigma_2)\Bigg\} - I(\sigma_0) - I(\sigma_1) - I(\sigma_2). \tag{22}$$

Using the first-order conditions $\frac{\partial E(SW)}{\partial \sigma_i} = 0$, we derive that the socially optimal R&D risk levels satisfy the following conditions:

$$\frac{8k^2-28k+23}{8(2-k)^2} = h(\sigma_0^s), \tag{23}$$

$$\frac{(1-k)\left[4f^2k^2(10k^2-33k+23)+2fk(4k^2-2k-18)+10k^2-33k+23\right]}{8(2-k)^2(1-2k)} = h(\sigma_i^s). \tag{24}$$

Here, σ_i^s denotes the socially optimal R&D risk level of firm i. Equation (23) corresponds to the outsider, while Equation (24) applies to the insiders ($i = 1, 2$). Comparing these with the private equilibrium conditions derived earlier yields the following proposition.

Proposition 8. *(i) The outsider's socially optimal risk exceeds its private choice: $\sigma_0^s > \sigma_0^n$; (ii) The insiders' socially optimal risk exceeds their private choice: $\sigma_i^s > \sigma_i^n$ ($i = 1, 2$).*

Proposition 8 implies that the equilibrium R&D risk for each firm (both insider and outsider) is systematically lower than the social optimum. In other words, firms exhibit an insufficient incentive for taking R&D risks.

To further investigate how cross-ownership affects this inefficiency, we assume a quadratic cost function $I(\sigma_i) = \sigma_i^2/2$ ($i = 0, 1, 2$) for analytical tractability. Our comparative statics analysis reveals distinct patterns for the outsider and insiders. For the outsider, we find that the gap between social and private optimality widens monotonically with cross-ownership, i.e., $\frac{\partial(\sigma_0^s - \sigma_0^n)}{\partial k} > 0$. For insiders, however, the response of the inefficiency gap is non-monotonic. Specifically, the gap widens ($\frac{\partial(\sigma_i^s - \sigma_i^n)}{\partial k} > 0$) when information sharing sensitivity f is large and cross-ownership k is at a moderate level, whereas it narrows in other parameter regions (see Figure 4.5). This result demonstrates that cross-ownership can exacerbate the distortion between private and social optima under specific conditions, notably when information sensitivity is high. This finding contrasts with Xing and Tan (2023), who suggest that cross-ownership generally reduces inefficiency.

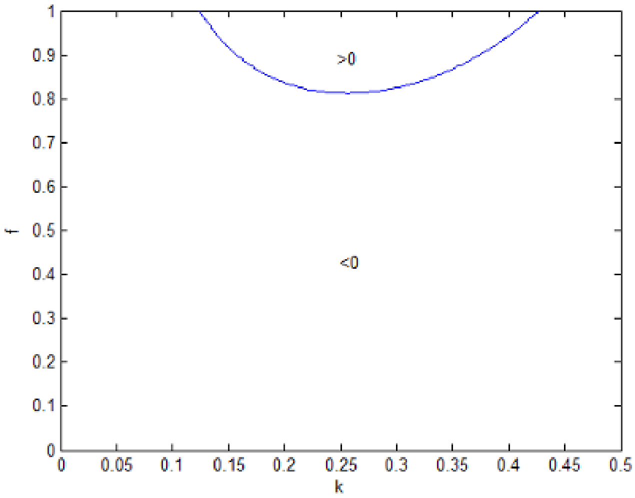

Figure 4.5: Sign of $\frac{\partial(\sigma_i^s - \sigma_i^n)}{\partial k}$, $(i = 1, 2)$.

The intuition behind Proposition 8 and the divergence analysis stems from the fundamental difference in objective functions between private firms and the social planner. First, private firms fail to internalize the consumer surplus effect. Successful risky R&D reduces marginal costs, which expands industry output and lowers prices, thereby increasing consumer surplus. While the social planner fully values this benefit, private firms only consider their own profits, leading to a baseline under-investment in risk.

Second, regarding the inefficiency gap (the distance between σ^s and σ^n), cross-ownership introduces competing forces. For the outsider, as k rises, the insider network becomes more cohesive and potentially aggressive in output (or less, depending on coordination), strategically suppressing the outsider's private incentive to innovate (σ_0^n decreases). However, from a social perspective, the outsider's innovation remains highly valuable to maintain variety and competition. This growing divergence causes the inefficiency gap $\sigma_0^s - \sigma_0^n$ to widen monotonically. For insiders, the gap is most pronounced when spillover sensitivity (f) is high and ownership (k) is moderate. In this region, high transparency creates a strong "appropriability problem" for private firms, discouraging them from taking risks (private incentives drop sharply due to leakage fears). However, the social planner values these spillovers positively as they represent efficient knowledge diffusion that lowers industry-wide costs. This clash—where spillovers are a private vice but a public virtue—maximizes the inefficiency gap. This nuance highlights that while cross-ownership aligns financial interests, it does not necessarily align private strategic choices with social welfare when information leakages are endogenous.

5 Concluding Remarks

This paper develops a Cournot triopoly model in which two firms hold mutual equity stakes (insiders), while the third firm (outsider) has no cross-ownership links. We examine how cross shareholding influences firms' R&D risk strategies through a dual mechanism: first, equity ties directly determine the extent of R&D information sharing among insiders; second, the resulting information spillover in turn shapes firms' R&D risk-taking behaviors. Notably, while insiders are connected through ownership, their R&D activities remain independent, without direct cooperation.

Our main findings are as follows. First, the R&D information-sharing sensitivity determines insiders' risk preference. When the sensitivity is weak, insiders display a stronger propensity for risk-taking than the outsider; however, when the sensitivity becomes strong, the relationship may reverse. Second, higher levels of cross-ownership among insiders suppress the outsider's R&D risk incentives, while their own responses exhibit nonlinear characteristics. Specifically, when its sensitivity on information sharing is weak, greater cross-ownership encourages higher R&D risk among insiders; when this sensitivity is strong, the relationship becomes U-shaped. These findings highlight the informational channel as a key transmission mechanism through which ownership structures shape innovation behavior.

We further extend the baseline model in two directions. First, introducing R&D cooperation between insiders reveals that such collaboration affects only firms within the network: under certain conditions, cooperation significantly dampens insiders' risk-taking incentives but does not influence the outsider's behavior. This asymmetry highlights the interplay between equity connections and cooperative behaviors. Second, when R&D information sharing is assumed to be independent of cross-ownership intensity, higher equity linkages unambiguously increase insiders' R&D risk motivation, suggesting that information sensitivity is the key moderating mechanism in the ownership–innovation relationship.

Overall, this study contributes to a deeper understanding of how cross-ownership networks influence firms' innovation risk-taking behavior, offering theoretical insights for both corporate strategy and antitrust policy in markets characterized by complex ownership interdependencies. To further elucidate the policy implications of our results, we compared the private equilibrium risk choices with the socially optimal levels that maximize total welfare (defined as the sum of consumer surplus and industry profits). Our analysis indicates that private firms consistently engage in "under-investment" in R&D risk compared to the social optimum. This inefficiency arises because private firms do not fully internalize the positive externalities of their successful innovations on consumer surplus and, in the non-cooperative case, on their rivals. Crucially, however, we find that the magnitude of this distortion—the gap between private and social optimality—is sensitive to the ownership structure. While cross-ownership generally helps internalize some business-stealing externalities, it interacts with information leakage in complex ways. Consequently, policymakers should recognize that while no ownership structure in this framework completely eliminates the under-investment problem, specific levels of cross-shareholding (particularly those that align incentives without triggering excessive transparency) may help narrow the gap between private strategic choices and the social ideal.

Despite these contributions, this study has several limitations that open promising avenues for future research. First, to maintain analytical tractability, we adopted simplifying assumptions including risk neutrality, linear demand functions, and exogenous mean returns to R&D. While these are standard in the literature to isolate the strategic effects of variance choice, future studies could explore how risk aversion or non-linear market demand might alter the magnitude of the risk-taking incentives derived here. Second, our model assumes symmetric passive cross-ownership and that knowledge spillovers are strictly confined to the insider network. In reality, ownership structures are often asymmetric, and knowledge may partially diffuse to outsiders. Relaxing these structural constraints—for instance, by modeling asymmetric holdings (see Xing and Lee (2025a)) or allowing for generalized industry-wide spillovers—would represent a significant extension of the current framework. Third, while this paper distinguishes between ownership (financial interest) and cooperation (joint maximization) among insiders, future research could explore alternative coalition structures, such as R&D cooperation between an insider and the outsider. Such an extension would clarify how the strategic effects of contractual alliances differ from those of equity linkages when the partners are not financially integrated. Fourth, many companies authorize their operations to managers, and thus it is necessary to further consider managerial delegation based on the framework of this study. Moreover, the model abstracts from potential dynamic effects of repeated interaction and learning, which may amplify or mitigate the informational advantages of cross shareholding over time. Future work could incorporate dynamic game frameworks or stochastic R&D processes to capture such effects. Moreover, our analysis assumes symmetric insiders and homogeneous products; relaxing these assumptions could yield richer implications for asymmetric ownership structures and differentiated markets.

Declarations

Funding Statement

The authors received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Statement

This article does not contain any studies with human participants or animals performed by any of the authors. Ethical approval was not required for this theoretical study.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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Appendix

Proof of Proposition 1

Substituting equations (14) and (15) into the difference $h(\sigma_0^n) - h(\sigma_i^n)$, we obtain:

$$\begin{aligned} h(\sigma_0^n) - h(\sigma_i^n) &= -\frac{4k^2(4k^3 - 13k^2 + 8k + 1)f^2 + 2k(-2k^2 + 4k - 6)f + 4k^3 - 13k^2 + 10k}{4(2-k)^2(1-2k)} \\ &\equiv \xi_1. \end{aligned}$$

By the mean value theorem, there exists $\sigma_a \in (\sigma_0^n, \sigma_i^n)$ such that $(\sigma_0^n - \sigma_i^n) \cdot h'(\sigma_a) = \xi_1$, where $h'(\sigma_a) = \frac{\partial^2 I(\sigma_i)}{\partial \sigma_i^2}\Big|_{\sigma_i = \sigma_a} > 0$ by assumption. It follows that $\text{sign}(\sigma_0^n - \sigma_i^n) = \text{sign}(\xi_1)$.

We now consider the sign of ξ_1 under different values of f: (1) When f is not large (e.g., $0 < f \leq 0.7$), it is straightforward to verify that $\xi_1 < 0$, which implies $\sigma_0^n < \sigma_i^n$. (2) When f is sufficiently large (e.g., $0.9 \le f \le 1$), the sign of ξ_1 depends on the value of k. Specifically, there exists a threshold $k_1(f) \in (0, 0.5)$ such that $\xi_1 = 0$ when $k = k_1(f)$ and

$$\xi_1 \begin{cases} > 0 & \text{if } k < k_1(f), \\ < 0 & \text{if } k > k_1(f). \end{cases}$$

Therefore, the sign of $\sigma_0^n - \sigma_i^n$ depends on the relative values of f and k, and Proposition 1 follows. □

Proof of Proposition 2

(i) Using equation (14), we have

$$h(\sigma_0^n) = \frac{(3-2k)^2}{4(2-k)^2}.$$

Differentiating with respect to k gives

$$h'(\sigma_0^n)\frac{\partial \sigma_0^n}{\partial k} = -\frac{(3-2k)}{2(2-k)^3} < 0.$$

Since

$$h'(\sigma_0^n) = \left.\frac{\partial^2 I(\sigma_0)}{\partial \sigma_0^2}\right|_{\sigma_0=\sigma_0^n} > 0,$$

it follows that

$$\frac{\partial \sigma_0^n}{\partial k} < 0.$$

(ii) Using equation (15), we obtain

$$h(\sigma_i^n) = \frac{2k^2(4k^3 - 13k^2 + 8k + 1)f^2 + 2k(-2k^2 + 4k - 6)f - 4k^3 + 15k^2 - 20k + 9}{4(2-k)^2(1-2k)}.$$

Differentiating with respect to k yields

$$h'(\sigma_i^n)\frac{\partial \sigma_i^n}{\partial k} = \frac{\xi_2}{2(1-2k)^2(2-k)^3},$$

where

$$\xi_2 = 4k(8k^5 - 51k^4 + 111k^3 - 89k^2 + 22k + 2)f^2 + (10k^3 - 4k^2 + 10k - 12)f + 3k^3 - 2k^2 - 7k + 7.$$

It can be shown that $\xi_2 > 0$ when f is small (or when f is large and $k > k_2(f)$), and $\xi_2 < 0$ when f is large and $k < k_2(f)$, where $k_2(f)$ satisfies $0 < k_2(f) < \frac{1}{2}$ and $\xi_2\big|_{k=k_2(f)} = 0$.

Since

$$h'(\sigma_i^n) = \left.\frac{\partial^2 I(\sigma_i)}{\partial \sigma_i^2}\right|_{\sigma_i=\sigma_i^n} > 0,$$

we obtain

$$\frac{\partial \sigma_i^n}{\partial k} \begin{cases} > 0, & \text{if } f \text{ is small,} \\ < 0\ (> 0), & \text{if } f \text{ is large and } k <\ (>)\, k_2(f). \end{cases}$$

□

Proof of Proposition 3

From (18) and (19), we have

$$h(\sigma_0^y) - h(\sigma_i^y) = \frac{4k^2(-2k^3+14k^2-22k+10)f^2 + 2k(4k^3-12k^2+20k-12)f + 6k^3-14k^2+8k+1}{4(2-k)^2(1-2k)}$$
$$\equiv \xi_3.$$

By the mean value theorem, there exists σ_b such that $(\sigma_0^y - \sigma_i^y)h'(\sigma_b) = \xi_3$. Since $h'(\sigma_b) = \left.\frac{\partial I^2(\sigma_i)}{\partial \sigma_i^2}\right|_{\sigma_i=\sigma_b} > 0$, it follows that

$$\text{sign}\{\sigma_0^y - \sigma_i^y\} = \text{sign}\{\xi_3\}.$$

We can verify that $\xi_3 < 0$ when f is not large (e.g., $0 < f \leq 0.7$). When f becomes sufficiently large (e.g., $0.9 \leq f \leq 1$), the sign of ξ_3 depends on the value of k: specifically, $\xi_3 > 0$ for $k_3(f) < k < k_4(f)$ and $\xi_3 < 0$ for $k < k_3(f)$ or $k > k_4(f)$, where $k_3(f)$ and $k_4(f)$ satisfy

$$0 < k_3(f) < k_4(f) < 0.5, \quad \xi_3\big|_{k=k_3(f)} = 0, \quad \xi_3\big|_{k=k_4(f)} = 0.$$

Hence, when f is large, $\sigma_0^y > \sigma_i^y$ holds for $k_3(f) < k < k_4(f)$, and $\sigma_0^y < \sigma_i^y$ otherwise. Therefore, Proposition 3 is proved. □

Proof of Proposition 4

(i) From (18), we have

$$h(\sigma_0^y) = \frac{(3-2k)^2}{4(2-k)^2}.$$

Differentiating both sides with respect to k yields

$$h'(\sigma_0^y)\frac{\partial \sigma_0^y}{\partial k} = -\frac{(3-2k)}{2(2-k)^3} < 0.$$

Because

$$h'(\sigma_0^y) = \frac{\partial^2 I(\sigma_0)}{\partial \sigma_0^2}\bigg|_{\sigma_0=\sigma_0^y} > 0,$$

it follows that $\dfrac{\partial \sigma_0^y}{\partial k} < 0$.
(ii) From (19), we obtain

$$h(\sigma_i^y) = \frac{(1-k)\left[(k^2-6k+5)(4k^2f^2+1)+4k(-k^2+2k-3)f\right]}{2(2-k)^2(1-2k)}.$$

Differentiating with respect to k gives

$$h'(\sigma_i^y)\frac{\partial \sigma_i^y}{\partial k} = \frac{\xi_4}{2(1-2k)^2(2-k)^3},$$

where

$$\begin{aligned}\xi_4 =& 4k(1-k)(4k^4-29k^3+79k^2-66k+20)f^2+(8k^5-56k^4+100k^3-104k^2\\ &+68k-24)f-5k^3+10k^2-13k+8.\end{aligned}$$

We can verify that $\xi_4 > 0$ when f is small (or when f is large and $k > k_5(f)$), and $\xi_4 < 0$ when f is large and $k < k_5(f)$, where $k_5(f)$ satisfies

$$0 < k_5(f) < 0.5, \qquad \xi_4\big|_{k=k_5(f)} = 0.$$

Since

$$h'(\sigma_i^y) = \frac{\partial^2 I(\sigma_i)}{\partial \sigma_i^2}\bigg|_{\sigma_i=\sigma_i^y} > 0,$$

we have

$$\frac{\partial \sigma_i^y}{\partial k} > 0 \quad \text{if } f \text{ is small}, \qquad \frac{\partial \sigma_i^y}{\partial k}\begin{cases} < 0, & \text{if } f \text{ is large and } k < k_5(f),\\ > 0, & \text{if } f \text{ is large and } k > k_5(f).\end{cases}$$

Therefore, Proposition 4 holds. □

Proof of Proposition 5

(i) From (14) and (18), we have

$$h(\sigma_0^y) - h(\sigma_0^n) = 0.$$

By the mean value theorem, there exists σ_c such that

$$(\sigma_0^y - \sigma_0^n)\, h'(\sigma_c) = 0.$$

Because

$$h'(\sigma_c) = \frac{\partial^2 I(\sigma_0)}{\partial \sigma_0^2}\bigg|_{\sigma_0=\sigma_c} > 0,$$

it follows immediately that $\sigma_0^y - \sigma_0^n = 0$.

(ii) From (15) and (19), we obtain

$$h(\sigma_i^y) - h(\sigma_i^n) = \frac{\xi_5}{4(2-k)^2},$$

where

$$\xi_5 = [6k(k-1)f + k + 1]\,[2k(k-3)f + 1 - k].$$

By the mean value theorem, there exists σ_d such that

$$(\sigma_i^y - \sigma_i^n)\,h'(\sigma_d) = \frac{\xi_5}{4(2-k)^2}.$$

Since

$$h'(\sigma_d) = \frac{\partial^2 I(\sigma_i)}{\partial \sigma_i^2}\bigg|_{\sigma_i=\sigma_d} > 0,$$

we have

$$\text{sign}\{\sigma_i^y - \sigma_i^n\} = \text{sign}\{\xi_5\}.$$

Analytical evaluation shows that $\xi_5 > 0$ when f is small (e.g., $0 < f \leq 0.2$). When f is sufficiently large (e.g., $0.3 \leq f \leq 1$), the sign of ξ_5 depends on k: specifically, $\xi_5 > 0$ for $k < k_6(f)$ and $\xi_5 < 0$ for $k > k_6(f)$, where $k_6(f)$ satisfies

$$0 < k_6(f) < 0.5, \qquad \xi_5\big|_{k=k_6(f)} = 0,$$

except for a narrow region where both f and k are sufficiently large. Hence, the comparative relationship between σ_i^y and σ_i^n follows the sign of ξ_5, and Proposition 5 is proved. □

Proof of Proposition 6

From (20) and (21), we have

$$h(\sigma_0^n) - h(\sigma_i^n) = -\frac{(4k^3 - 13k^2 + 8k + 1)b^2 + (-2k^2 + 4k - 6)b + 4k^3 - 13k^2 + 10k}{4(2-k)^2(1-2k)} \equiv \xi_6.$$

By the mean value theorem, there exists σ_e such that

$$(\sigma_0^n - \sigma_i^n)\,h'(\sigma_e) = \xi_6.$$

Because

$$h'(\sigma_e) = \left. \frac{\partial^2 I(\sigma_i)}{\partial \sigma_i^2} \right|_{\sigma_i = \sigma_e} > 0,$$

it follows that

$$\text{sign}\{\sigma_0^n - \sigma_i^n\} = \text{sign}\{\xi_6\}.$$

Analytical evaluation shows that

$$\xi_6 < 0 \quad \text{if } b = 0, \qquad \xi_6 > 0 \quad \text{if } b = 1.$$

For intermediate values $0 < b < 1$, the sign of ξ_6 depends on k: specifically, $\xi_6 > 0$ when $k < k_7(b)$ and $\xi_6 < 0$ when $k > k_7(b)$, where $k_7(b)$ satisfies

$$0 < k_7(b) < 0.5, \qquad \xi_6\big|_{k=k_7(b)} = 0.$$

Hence, the relative magnitude of σ_0^n and σ_i^n is determined by the sign of ξ_6, and Proposition 6 is proved. □

Proof of Proposition 7

(i) From (20), we have

$$h(\sigma_0^n) = \frac{(3-2k)^2}{4(2-k)^2}.$$

Differentiating both sides with respect to k yields

$$h'(\sigma_0^n)\,\frac{\partial \sigma_0^n}{\partial k} = -\frac{(3-2k)}{2(2-k)^3} < 0.$$

Because

$$h'(\sigma_0^n) = \left. \frac{\partial^2 I(\sigma_0)}{\partial \sigma_0^2} \right|_{\sigma_0 = \sigma_0^n} > 0,$$

it follows that $\dfrac{\partial \sigma_0^n}{\partial k} < 0$.

(ii) From (21), we obtain

$$h(\sigma_i^n) = \frac{(4k^3 - 13k^2 + 8k + 1)b^2 + (-2k^2 + 4k - 6)b - 4k^3 + 15k^2 - 20k + 9}{4(2-k)^2(1-2k)}.$$

Differentiating with respect to k gives

$$h'(\sigma_i^n)\,\frac{\partial \sigma_i^n}{\partial k} = \frac{\xi_7}{2(1-2k)^2(2-k)^3},$$

where

$$\xi_7 = (-5k^3 + 22k^2 - 25k + 11)b^2 + (2k^3 - 4k^2 + 16k - 14)b + 3k^3 - 2k^2 - 7k + 7.$$

Since

$$h'(\sigma_i^n) = \left.\frac{\partial^2 I(\sigma_i)}{\partial \sigma_i^2}\right|_{\sigma_i = \sigma_i^n} > 0,$$

the sign of $\frac{\partial \sigma_i^n}{\partial k}$ is determined by that of ξ_7. For the parameter range considered, $\xi_7 > 0$ holds, implying

$$\frac{\partial \sigma_i^n}{\partial k} > 0.$$

Therefore, Proposition 7 is proved. □

Proof of Proposition 8

(i) From (14) and (23), we have

$$h(\sigma_0^s) - h(\sigma_0^n) = \frac{5 - 4k}{8(2-k)^2} > 0.$$

By the mean value theorem, there exists σ_f such that

$$(\sigma_0^s - \sigma_0^n)h'(\sigma_f) = \frac{5 - 4k}{8(2-k)^2} > 0.$$

Because

$$h'(\sigma_f) = \left.\frac{\partial I^2(\sigma_0)}{\partial \sigma_0^2}\right|_{\sigma_0 = \sigma_f} > 0, \qquad \sigma_0^s - \sigma_0^n > 0.$$

(ii) From (15) and (24), we have

$$h(\sigma_i^s) - h(\sigma_i^n) = \frac{12k^2(3k^2 - 10k + 7)f^2 + 4k(k^2 - 2k - 3)f + k^2 - 6k + 5}{8(2-k)^2} = \xi_8 > 0.$$

By the mean value theorem, there exists σ_g such that

$$(\sigma_i^s - \sigma_i^n)h'(\sigma_g) = \xi_8 > 0.$$

Because

$$h'(\sigma_g) = \left.\frac{\partial I^2(\sigma_i)}{\partial \sigma_i^2}\right|_{\sigma_i = \sigma_g} > 0,$$

$$\sigma_i^s - \sigma_i^n > 0. \quad \square$$