Equity Holding, Technology Sharing and Supplier Investment

Guozhao Cao[*], Kaili Song

School of Economics and Management, Shanxi Univesity, Taiyuan, China
*Corresponding author: caoguozhao@sxu.edu.cn

Abstract Consider a supply chain consists of one supplier and two manufactures, we discuss the influence of manufacturer's technology sharing on supplier's technology investment decision, and the impact of equity holding on the first two by constructing a multi-stage game between a supplier and two manufacturers. The results show that when the investment cost is relatively high, the manufacturer will choose to open technology to induce supplier investment in open technology. Otherwise, it will choose to close technology to force the supplier investment in both technologies. We also find that when the spillover effect is small, the probability that the manufacturer choosing to open technology and the supplier investing in the open technology decreases first and then increases with the shareholding ratio.

Cite This Article: Guozhao Cao, and Kaili Song, "Equity Holding, Technology Sharing and Supplier Investment." *Journal of Finance and Economics*, vol. 9, no. 2 (2021): 73-76. doi: 10.12691/jfe-9-2-4.

1. Introduction

In the automotive industry, many suppliers hold shares in manufacturers [1] to lock up sales and occupy long-term market shares. They may also invest in new technologies to promote the industry development. However the supplier may face uncertainty in the development process. Holding shares in manufacturers can align the interest of both sides and encourage the supplier to make special investment. On the other hand, manufactures may open their technologies to promote supplier investment, and increase market share. Meanwhile it will lead to fierce competition as more firms enter the market.

Greenlee and Raskovich [2] showed that a backward ownership interest held by a downstream firm yields a partial rebate of the upstream margin. Fu et al. [3] studied supplier's investment in manufacturer's quality improvement with equity holding and showed that the investment can always increase the market demand. However, they did not consider technology sharing. Hu et al. [4] studied the innovation spillover in outsourcing, showed that the innovator may strategically outsource to a competitor in both technical and non-technical innovation. Hu et al. [5] studied technology sharing and supplier investment under competition, showed that technology sharing may promote supplier investment sometimes. This study is most similar to ours, but it did not consider equity holding. Aviv et al. [6] studied the impact of cross-shareholding among retailers on information transmission and showed that holding shares of competitors could reduce the level of

competition. However they did not consider vertical ownership. Therefore, based on the above researches, this paper focuses on manufacturer's technology sharing and supplier's technology investment decision under equity holding, aims to discuss the relationship between them, enriches the related researches.

2. Problem Description

To solve the above problems, we consider a supply chain contains 1 supplier S and 2 competing manufacturers M1 and M2. The manufactures both have their own proprietary technology. M1 may open its own technology T1 to M2. S holds shares in M1. The sequence of events is as follows: First, supplier S decides its number of shares in manufacturer M1. Second, manufacturer M1 decides whether to open its technology to manufacture M2. Third, S decides which technology to invest in. Fourth, after the demand is realized, M2 decides which technology to adopt. Finally, supplier S determine the wholesale price, manufacturers M1 and M2 determine their order quantities.

3. Model Analysis

3.1. Supplier's Investment Decision

3.1.1. M1 Chooses to Open Technology T1

In this scenario, supplier S can choose to invest in neither technology, invest in technology T1, or invest in both technologies.

(1) Invest in neither technology

In this case, every player receives 0 profits:

$$\pi_{s,2}^O = \pi_{m1,2}^O = \pi_{m2,2}^O = 0.$$

(2) Invest in technology T1

In this case, M2 can adopt T1. Due to spillover, the overall market size becomes $\hat{A} = A + \gamma(1-A)$, $\pi_{m1,4}^O = (1-\lambda)(\hat{A} - q_1 - q_2 - \omega_1)q_1$, $\pi_{m2,4}^O = (\hat{A} - q_1 - q_2 - \omega_1)q_2$. Set $d\pi_{m1,4}^O / dq_1 = 0$, $d\pi_{m2,4}^O / dq_2 = 0$ we can get $q_1^* = q_2^* = (\hat{A} - \omega_1)/3$, $\pi_{s,4}^O = \omega_1(q_1 + q_2) + \lambda(\hat{A} - \omega_1)^2/9$. Substituting q_1^* and q_2^* into $\pi_{s,4}^O$, and set $\partial\pi_{s,4}^O / \partial\omega_1 = 0$, we can get $\omega_1^* = (3-\lambda)\hat{A}/(6-\lambda)$. Substituting ω_1^*, q_1^* and q_2^* into $\pi_{m1,4}^O$, $\pi_{m2,4}^O$, $\pi_{s,4}^O$, we can get $\pi_{m1,4}^O = (1-\lambda)\hat{A}^2/(6-\lambda)^2 \geq 0$, $\pi_{m2,4}^O = \hat{A}^2/(6-\lambda)^2 \geq 0$, $\pi_{s,4}^O = \hat{A}^2/(6-\lambda)$. So if S invest in T1, M2 will adopt T1. $\pi_{s,2}^O = E[\pi_{s,4}^O] - K = (1+\gamma+\gamma^2)/[3(6-\lambda)] - K = L1 - K$, $\pi_{m1,2}^O = (1-\lambda)(1+\gamma+\gamma^2)/[3(6-\lambda)^2]$, $\pi_{m2,2}^O = (1+\gamma+\gamma^2)/[3(6-\lambda)^2]$.

(3) Invest in both technologies

In this case, there are 2 situations:

a. M2 chooses T1. Then the profits of each player in stage 4 is: $\pi_{m1,4}^{Oa} = (1-\lambda)\hat{A}^2/(6-\lambda)^2$, $\pi_{m2,4}^{Oa} = \hat{A}^2/(6-\lambda)^2$, and $\pi_{s,4}^{Oa} = \hat{A}^2/(6-\lambda)$ respectively.

b. M2 chooses T2. Then the profit of each player is $\pi_{m1,4}^{Ob} = (1-\lambda)A^2/[4(2-\lambda)^2]$, $\pi_{m2,4}^{Ob} = (1-A)^2/16$ and $\pi_{s,4}^{Ob} = (1-\lambda)(2+\lambda)A^2/[4(2-\lambda)^2] + (1-A)^2/8$. By comparing a and b, we can get that if and only if $\hat{A}^2/(6-\lambda)^2 \geq (1-A)^2/16$, i.e. $A \geq (6-\lambda-4\gamma)/[6-\lambda+4(1-\gamma)] = \tilde{A}$, M2 will adopt T1, otherwise it will adopted T2. Therefore, the profits of each player is:

$$\pi_{m1,2}^O = \int_0^{\tilde{A}} \pi_{m1,4}^{Ob}dA + \int_{\tilde{A}}^1 \pi_{m1,4}^{Oa}dA$$

$$= 4(1-\lambda)/\{(6-\lambda)[6-\lambda+4(1-\gamma)]^2\}$$

$$+ (1-\lambda)/\left\{3\begin{bmatrix}6-\lambda\\+4(1-\gamma)\end{bmatrix}^3\right\}\left\{\begin{array}{l}64(1-\gamma)^2/(6-\lambda)^2\\+(6-\lambda-4\gamma)^3/[4(2-\lambda)^2]\end{array}\right\}$$

$$\pi_{m2,2}^O = \int_0^{\tilde{A}} \pi_{m2,4}^{Ob}dA + \int_{\tilde{A}}^1 \pi_{m2,4}^{Oa}dA$$

$$= (6-\lambda-4\gamma)^3/\{48[6-\lambda+4(1-\gamma)]^3\}$$

$$+ (6-\lambda-4\gamma)/\{4[6-\lambda+4(1-\gamma)]^2\}$$

$$+ 4/\left\{3(6-\lambda)^2\begin{bmatrix}6-\lambda\\+4(1-\gamma)\end{bmatrix}\right\}\left\{\begin{array}{l}3(6-\lambda)/[6-\lambda+4(1-\gamma)]\\+16(1-\gamma)^2/\begin{bmatrix}6-\lambda\\+4(1-\gamma)\end{bmatrix}^2\end{array}\right\}$$

$$\pi_{s,2}^O = \int_0^{\tilde{A}} \pi_{s,4}^{Ob}dA + \int_{\tilde{A}}^1 \pi_{s,4}^{Oa}dA - 2K$$

$$= (14-\lambda-4\gamma)/\{2[6-\lambda+4(1-\gamma)]^2\}$$

$$+ (4-3\lambda+\lambda^2)(6-\lambda-4\gamma)^3/\left\{12(2-\lambda)^2\begin{bmatrix}6-\lambda\\+4(1-\gamma)\end{bmatrix}^3\right\}$$

$$+ 64(1-\gamma)^2/\{3(6-\lambda)[6-\lambda+4(1-\gamma)]^3\} - 2K$$

$$= L2 - 2K.$$

Comparing the above three cases, we can get the investment decision of S as proposition 1.

Proposition 1: If M1 chooses to open technology, S will invest in neither technology when $K > L_1$. It will invest in T1 when $L_2 - L_1 < K \leq L_1$. It will invest in both technologies when $K \leq L_2 - L_1$.

Proof: According to (2) and (3), S will choose to invest in T1 when $K \leq L_1$ and both technologies when $K \leq L_2/2$. We can prove that $L_1 > L_2/2$, so S will invest in neither technology when $K > L_1$. It will invest in T1 when $L_2/2 < K \leq L_1$. When $K \leq L_2/2$, it is necessary to compare the expected profit of S when it invest in both technologies and T1. When $L_1 - K > L_2 - 2K$, S will invest in T1, otherwise, it will invest in both technologies, we can prove $L_2 - L_1 < L_2/2$. Therefore, Proposition 1 is proved.

Proposition 1 proves that if M1 chooses to open technology, S will invest in neither technology when K is high. It will invest in both technologies when K is low. Otherwise it will invest in T1.

3.1.2. M1 Chooses to Close Technology

In this case, S can choose to invest in neither technology, invest in technology T1, or invest in both technologies.

(1) Invest in neither technology

In this case, every player receives 0 profits: $\pi_{s,2}^C = \pi_{m1,2}^C = \pi_{m2,2}^C = 0$.

(2) Invest in technology T1

In this case, $\pi_{m1,4}^C = (1-\lambda)(A - q_1 - \omega_1)q_1$. Set $d\pi_{m1,4}^C / dq_1 = 0$, we can get $q_1^* = (A - \omega_1)/2$. $\pi_{s,4}^C = \omega_1 q_1 + \lambda(A - \omega_1)^2/4$, substitute q_1^* into $\pi_{s,4}^C$ and set $\partial\pi_{s,4}^C / \partial\omega_1 = 0$, we can obtain $\omega_1^* = (1-\lambda)A/(2-\lambda)$. Substitute ω_1^* and q_1^* into the profit of each player, we can get $\pi_{m1,4}^C = (1-\lambda)A^2/[4(2-\lambda)^2]$, $\pi_{s,4}^C = (1-\lambda)(2+\lambda)A^2/[4(2-\lambda)^2] \geq 0$. So if S invest in T1, M1 will introduce its product to the market. $\pi_{m1,2}^C = (1-\lambda)/[12(2-\lambda)^2]$, $\pi_{m2,2}^C = 0$, $\pi_{s,2}^C = (1-\lambda)(2+\lambda)/[12(2-\lambda)^2] - K = L3 - K$.

(3) Invest in both technologies

In this case, $\pi_{m1,4}^C = (1-\lambda)(A-q_1-\omega_1)q_1$, $\pi_{m2,4}^C = (1-A-q_2-\omega_2)q_2$, set $d\,\pi_{m1,4}^C/d\,q_1 = 0$, $d\,\pi_{m2,4}^C/d\,q_2 = 0$, we can get $q_1^* = (A-\omega_1)/2$, $q_2^* = (1-A-\omega_2)/2$. $\pi_{s,4}^C = \omega_1 q_1 + \omega_2 q_2 + \lambda(A-\omega_1)^2/4$, substitute q_1^* and q_2^* into $\pi_{s,4}^C$, set $\partial\pi_{s,4}^C/\partial\omega_1 = 0$, $\partial\pi_{s,4}^C/\partial\omega_2 = 0$, we can get $\omega_1^* = (1-\lambda)A/(2-\lambda)$, $\omega_2^* = (1-A)/2$. Substituting ω_1^* , ω_2^* , q_1^* and q_2^* into $\pi_{m1,4}^C$, $\pi_{m2,4}^C$ and $\pi_{s,4}^C$ we can get $\pi_{m1,4}^C = (1-\lambda)A^2/[4(2-\lambda)^2] \ge 0$,
$\pi_{m2,4}^C = (1-A)^2/16 \ge 0$,

$$\pi_{s,4}^C = (1-\lambda)(2+\lambda)A^2/[4(2-\lambda)^2] + (1-A)^2/8.$$

So $\pi_{m1,2}^C = (1-\lambda)/[12(2-\lambda)^2]$, $\pi_{m2,2}^C = 1/48$, $\pi_{s,2}^C = (8-6\lambda-\lambda^2)/[24(2-\lambda)^2] - 2K = L_4 - 2K$ when S invest in T1 and T2.

Comparing the above three cases, we can obtain S's technology investment decision as Proposition 2.

Proposition 2: If M1 chooses to close technology, S will invest in neither technology if $K > L_3$. It will invest in T1 if $L_3 \ge K > 1/24$. It will invest in T1 and T2 if $K \le 1/24$.

Proof: According to (2) and (3), S will invest in T1 when $K \le L_3$. S will invest in both technologies when $K \le L_4/2$. We can prove that $L_3 > L_4/2$, so when $K > L_3$, S will invest in neither technology. When $L_4/2 < K \le L_3$, S will invest in T1. When $K \le L_4/2$, the expected profit of S when it invest in T1 and T2 is compared with that when it invest in T1. When $L_3 - K > 2L_4 - 2K$, S will invest in T1. Otherwise, it will invest in both technologies. Comparing L_3 , $L_4/2$ and $1/24$, we can get that $L_3 > L_4/2 > 1/24$. Therefore, Proposition 2 is proved.

Proposition 2 proves that if M1 chooses to close technology, S will invest in neither technology when K is high. It will invest in both technologies when K is low. Otherwise, it will invest in technology T1.

3.2. Manufacturer's Technology Sharing Decision

According to the analysis in 3.1, we can get M1's technology sharing decision in stage 1 as the Theorem:

Theorem: (1) If $L_3 \le K < L_1$, manufacturer M1 chooses to open technology, the supplier invest in T1.

(2) If $L_2 - L_1 \le K < L_3$, M1 chooses to open technology and the supplier invest in T1 when $\gamma \ge \sqrt{24-2\lambda^2}/[2(2-\lambda)] - 1/2 = \tilde{\gamma}$, otherwise M1 close T1 and the supplier invest in both technologies.

(3) If $0 \le K < L_2 - L_1$, M1 chooses to close technology and the supplier invest in both technologies.

Proof: (1) If $L_3 \le K < L_1$, $\pi_{m1,2}^O = (1-\lambda)(1+\gamma+\gamma^2)/[3(6-\lambda)^2]$ when M1 choose to open T1. $\pi_{m1,2}^C = 0$ otherwise, so M1 choose to open technology.

(2) If $L_2 - L_1 \le K < L_3$, $\pi_{m1,2}^O = (1-\lambda)(1+\gamma+\gamma^2)/[3(6-\lambda)^2]$, $\pi_{m1,2}^C = (1-\lambda)/[12(2-\lambda)^2]$. Comparing $\pi_{m1,2}^O$ and $\pi_{m1,2}^C$, we can conclude that when $\gamma \ge \tilde{\gamma}$, M1 will chooses to open T1. Otherwise it will close T1.

(3) When $0 \le K < L_2 - L_1$,

$$\pi_{m1,2}^O = 4(1-\lambda)/\{(6-\lambda)[6-\lambda+4(1-\gamma)]^2\}$$
$$+ (1-\lambda)\begin{bmatrix} 64(1-\gamma)^2/(6-\lambda)^2 \\ +(6-\lambda-4\gamma)^3/4(2-\lambda)^2 \end{bmatrix}/3[6-\lambda+4(1-\gamma)]^3.$$

$\pi_{m1,2}^C = (1-\lambda)/[12(2-\lambda)^2]$. Comparing $\pi_{m1,2}^O$ and $\pi_{m1,2}^C$, we can get $\pi_{m1,2}^O < \pi_{m1,2}^C$, so M1 chooses to close technology.

According to the Theorem, M1 chooses to close technology when K is relatively low. When K is at an intermediate level, but γ is large, M1 chooses to open technology, when γ is small, M1 chooses to close technology. M1 chooses to open technology when K is relatively high.

4. Numerical Experiments

Since the expression of manufacturer's technology sharing decision boundary is abstract and complex, we use numerical experiment to verify the above Theorem. The boundary of manufacturer's technology sharing decision is shown in Figure 1 and Figure 2 according to the Theorem:
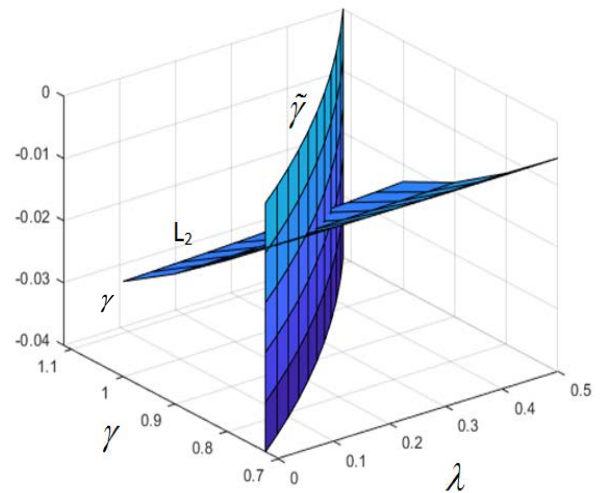

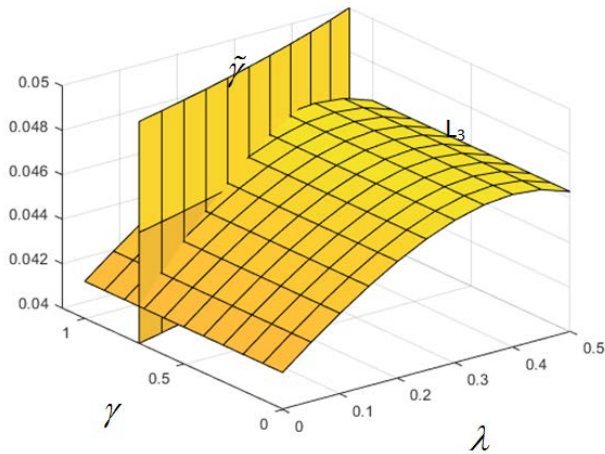**Figure 2.** manufacturer technology sharing decision when $\gamma \ge \tilde{\gamma}$

Figure 3. manufacturer technology sharing decision when $\gamma < \tilde{\gamma}$

According to the Theorem, when $\gamma \geq \tilde{\gamma}$, the boundary condition for the manufacturer choosing to close technology is $K < L_2$. As can be seen from Figure 1, $L_2 < 0$. Therefore, as long as $0 \leq K < L_1$, the manufacturer will always choose to open technology. When $\gamma < \tilde{\gamma}$, the boundary condition for the manufacturer choosing to close technology is $K < L_3$. As can be seen from Figure 2, L_3 first increases and then decreases with the shareholding ratio, so it can be concluded that the probability of the manufacturer choosing to close technology first increases and then decreases with the shareholding ratio.

5. Conclusion

This paper studies the relationship between equity holding, supplier investment and technology sharing. The results show that: First, when the investment cost K is relatively high, M1 chooses to open technology to encourage the supplier to invest in open technology. When K is relatively low, M1 will choose to close technology to force the supplier to invest in the two closed technologies. Second, when the spillover effect is large, the manufacturer will always choose to open technology and the supplier will always invest in the open technology. Third, when the spillover effect is small, the probability of the manufacturer choosing to open technology and the supplier choosing to invest in T1 decreases first and then increases with the shareholding ratio.

References

[1] Patrick G, Alexander R. *Partial vertical ownership[J]*. European Economic Review, 2006, 50: 1017-1041.

[2] H Fu, M Liu, B Chen. *Supplier's investment in manufacturer's quality improvement with equity holding[J]*. Journal of Industrial and Management Optimization, 2021, 17(2): 649-668.

[3] B Hu, Y Mai, S Pekec. *Managing innovation Spillover in Outsourcing[J]*. Production and Operations Management, 2020, 29(10): 2252-2267.

[4] B Hu, M Hu, Y Yang. *Open or closed? Technology sharing, supplier investment, and competition[J]*. Manufacturing Service & Operations Management, 2017, 19(1): 132-149.

[5] Y Aviv, N Shamir. Financial Cross-Ownership and Information Dissemination in a Supply Chain[J]. Manufacturing Service & Operations Management, 2020, Articles in advance.