Free licensing strategy and ex post privatization in a mixed oligopoly

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Abstract

This paper investigates free licensing strategy with a flexible privatization policy in a mixed oligopoly in which licensing contracts are observable before the government chooses its optimal degree of ex post privatisation. We examine and compare foreign and public licensors and explore the strategic relationship between the foreign share of passive ownership in domestic firms and the cost efficiency gap between licensor and licensee. We show that licensing strategies always yield more privatization and higher welfare, but the incentive for free licensing between the foreign licensor and public licensor differ. We also consider open technology, where all firms have the same technology and find a contrasting result. The optimal degree of privatization under open technology is the lowest (highest) under foreign (public) licensing contracts.

Keywords: free licensing; foreign licensing; public licensing; technology gap; passive ownership; flexible privatization; optimal privatization; open technology

1. Introduction

As globalization advances, many firms utilize their rival's advanced technologies by paying license fees (or even under free licensing) instead of directly reducing production costs through R&D. We can observe different types of technology sharing in various industries in the real world. For example, the CSIRO licensed new medical polymer technologies to PolyNovo in 2005 (Niu, 2017).[1] BMW licensed its engine technology to a Chinese state-owned enterprise, Dongfeng, to produce Motor Corporation, Fengxing T5 SUV in 2018. Additionally, US-based Tesla implemented an open technology by opening its patent rights related to electric vehicles without any fees in 2014. Accordingly, Toyota also opened its Fuel Cell Vehicle (FCV) patents technology in 2015.[2] We can find these different forms of free licensing strategies among both private and public licensors.

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[1] The CSIRO (Commonwealth Scientific and Industrial Research Organisation) is an Australian government agency responsible for scientific research and PolyNovo is a biotechnology partner and company created by the CSIRO.
[2] Toyota Motor Corporation will allow royalty-free use of approximately 5,680 of its FCV-related patent licenses. Toyota believes it is important to prioritise the widespread use of FCVs at the initial introduction stage.

Many global firms also diversify their risk by holding some stakes in domestic competitors to gain an edge over the competition. In this process, we sometimes see that shareholders do not exercise their ownership, which is known as passive ownership.[3] This situation often arises in a competitive market partially because it can reduce the risk of doing business. For example, if shareholders actively use ownership power with shareholder votes, then they may harm domestic welfare by their strengthened market power. Thus, the government can impose legal sanctions to weaken such monopoly power.

Despite the global trend of liberalization, many public enterprises with significant government ownership are still active in strategic sectors and control large portions of the world's resources. They are significant players in mixed oligopolistic sectors such as transportation, telecommunications, energy, and finance in OECD countries, where public enterprises compete with private enterprises.[4] Since the 1980s, however, privatization in these industries attracted extensive policy attention from economics researchers in developed, developing, and transitional economies such as Eastern Europe, Latin America, and Asia, including China.

The relationship that technology transfer by foreign firms affects in privatization is a crucial issue in a mixed oligopoly under passive ownership.[5] However, little attention has been paid to the relationship between technology transfer with passive ownership and privatization. There are a few theoretical papers that combine the issues of technology transfer with licensing contracts in a mixed oligopoly. Mukherjee and Sinha (2014) show that technology licensing cannot bridge the efficiency difference and confirms the possibility of partial privatization. Wang and Zeng (2019) and Wang et al. (2020) examine how licensing contracts from an efficient private firm (or public firm) to either a public firm or a private (domestic or foreign) firm affects privatization. They demonstrate that licensing to the private firm provides further motivation for privatization, while licensing to the public firm reduces the incentives for privatization compared to foreign licensing. Haraguchi and Matsumura (2020a) also examine

[3] Passive ownership refers to any shareholder in a business who is not involved in the firm's operational decision-making, which might require shareholder votes. We currently see interest from researchers and policymakers regarding the impact of passive ownership in rival firms. For recent works on the competitive and anticompetitive effects of passive ownership, see Li et al. (2015), Schmalz (2018) and Papadopoulos et al. (2019).

[4] According to an OECD report by Kowalski et al. (2013), more than 10% of the 2000 largest companies are public enterprises with sales equivalent to approximately 6% of worldwide GDP. In particular, public enterprises still have a significant presence and compete with private enterprises in planned and transitional countries such as China, Vietnam, and Russia. For some evidence from Asian countries such as Japan, China, Vietnam and so on, see Huang and Yang (2016), Chen (2017), Fridman (2018), Lee et al. (2018), Kim et al. (2019) and Xu et al. (2017, 2020).

[5] The recent decade witnessed increasing application of mixed oligopoly frameworks in which domestic public and foreign private firms compete in the market. Previous studies investigated the effect of the introduction of foreign private firms on market prices and welfare. For example, Pal and White (2003), Yu and Lee (2011), Lee et al. (2013), Xu and Lee (2015) and Cato and Matsumura (2015) discussed the relationship between privatization and trade policies, while Lin and Matsumura (2012), Cato and Matsumura (2012) and Xu et al. (2017) considered foreign penetration of the private firm's ownership. Regarding licensing issues, see Ye (2012), Chen et al. (2014), Niu (2015) and Kim et al. (2018)

technology licensing between foreign-owned private firms and show that technology transfer will likely occur in only one direction, in which domestic enterprises do not transfer technology to foreign enterprises even if domestic enterprises have superior knowledge. They further find that privatization motivates voluntary technology transfer from foreign to domestic firms.

In this paper, we investigate a free licensing strategy in which a licensor transfers technology voluntarily to a domestic firm, though it will face potential privatizaion in the future.[6] In a sequential game where the licensor can determine the free licensing contract first and then the government chooses its optimal degree of ex post privatization, we examine and compare foreign licensing and public licensing, respectively, in a mixed oligopoly where a public firm competes with two private firms, one domestic and one foreign. We explore the strategic relationship between the foreign share of passive ownership in domestic firms and the cost efficiency gap between licensor and licensee. We show that licensing strategies always yield more privatization and higher welfare. Our results reveal that the existence of a public firm and potential future privatization encourages voluntary technology transfers from the licensor to the domestic private firm. The easing of privatization induced by free licensing will also mitigate competition in the market but increase social welfare.

The main findings of this paper are as follows. When the licensor transfers its advanced technology to the domestic firm, the licensee's production cost reduction accelerates competition in the production market, which induces the government to increase the degree of privatization. Consequently, free licensing can increase the domestic private firm's profit and welfare, but the incentive for free licensing between the foreign licensor and the public licensor differs. On the one hand, the foreign licensor will perceive that the government is implementing more privatization, while passive ownership of the domestic firm is essential to determine free licensing. Therefore, with a significant amount of foreign ownership, the easing of privatization induced by free licensing will increase social welfare. On the other hand, the public licensor can choose free licensing only when the cost gap is relatively low irrespective of the foreign ownership share.

We also show that the optimal degree of privatization under foreign licensing is always higher than that under public licensing. This finding implies that the foreign licensor creates more motivation for privatization, but state-owned enterprises may act as implicit industrial policies to extract advanced technologies from foreign firms to improve the productivity of domestic firms or to prevent the outflow of domestic capital to foreign countries by improving the productivity of domestic firms.

Finally, we consider open technology where all firms have the same technology and show a contrasting result: the optimal degree of privatization under open technology is the lowest (highest)

[6] Regarding the welfare effects of ex post privatization when the government lacks commitment, see Xu et al. (2017), Lee et al. (2018), Chen et al. (2019) and Haraguchi and Matsumura (2020b).

under foreign (public) licensing contracts. However, both foreign and public licensors do not adopt open technology even if it can be socially desirable. It is therefore necessary for the government to induce the licensor to implement open technology under certain regulations.

The organization of the paper is as follows. Section 2 presents the basic model. We examine voluntary technology transfer by a foreign licensor and a public licensor in Sections 3 and 4, respectively. In Section 5, we compare the two licensing strategies and discuss the welfare effect of open technology. Section 6 concludes.

2. The basic model

We consider a mixed triopoly market in which one public firm (firm 0) and two private firms (firm 1 and 2) compete in a Cournot fashion. Each firm produces homogeneous products, q_i $(i = 0, 1, 2)$, with an inverse linear demand function.

$$p(Q) = a - Q, \tag{1}$$

where p is the market price and $Q = \sum_{i=0}^{2} q_i$ is total output. The cost function of each firm is denoted by $C(q_i) = k_i q_i^2$, where k_i represents the cost efficiency parameter of the firm, $i = 0, 1, 2$.

The profit function of each firm is defined as

$$\pi_i = p(Q)q_i - C_i(q_i). \tag{2}$$

We assume that firm 0 is a semi-public firm that can be (partially) privatized by the government and both firms 1 and 2 are private firms, where firm 1 is a domestic firm and firm 2 is a foreign firm, respectively. We further assume that firm 2 owns a portion of the shares of firm 1, $\beta \in [0, 1)$, with the silent financial form of passive ownership; that is, the foreign firm has passive partial ownership in the domestic firm, which implies that foreign shareholders do not affect the production decisions of firm 1.

Social welfare is the sum of the consumer surplus and domestic firms' profits.

$$W = \frac{1}{2}Q^2 + \pi_0 + (1 - \beta)\pi_1. \tag{3}$$

Each firm has different objective functions. Following Matsumura (1998), firm 0 is a public firm that maximizes V_0, which is a convex combination of social welfare and its own profit.

$$V_0 = (1 - \theta)W + \theta\pi_0, \tag{4}$$

where $\theta \in [0, 1]$ represents the degree of privatization determined by the welfare-maximizing government.

Because domestic firm 1 operates under passive ownership, it can maximize its own profit without direct interruption from firm 2. That is, the objective of firm 1 is

$$V_1 = (1-\beta)\pi_1, \tag{5}$$

where $\beta \in [0,1)$ is the ratio of foreign ownership. Note that maximization of V_1 is equivalent to maximizing π_1. The foreign firm 2 maximizes its total profits.

$$V_2 = \pi_2 + \beta\pi_1. \tag{6}$$

Finally, we consider a free licensing contract between the licensor (efficient firm) and licensee (inefficient firm) under different cost efficiency parameters among the firms, where $k_i \in [0,1]$. For simplicity, we assume that an efficient firm has $k_i = \mathrm{k} \in [0,1)$, while an inefficient firm has $k_i = 1$, which denotes the standard level of technology. That is, k represents the relative technical gap between the licensor and licensee. We assume that the cost condition under a free licensing contract becomes $k_{Licensor} = k_{Licensee} = k < k_{Standard} = 1$. This condition implies that if a licensor transfers its advanced technology to its rival firm, then a licensee produces outputs with the same efficiency.[7]

Below, we consider two different forms of free licensing contracts: foreign licensing and public licensing.[8] In the former, we examine whether the foreign firm intends to transfer its advanced technology to rival firm 1, of which shares are partially owned by the licensor. In the latter, we examine whether the public firm intends to transfer technology to domestic firm 1 but not foreign firm 2, of which profit is also taken into the objectives of the licensor.

The game runs as follows. In the first stage, the licensor independently chooses whether to transfer to the rival firm. In the second stage, the government chooses the optimal degree of privatization.[9] In the third stage, each firm simultaneously chooses its output to maximize its objectives in a Cournot fashion. We solve the game by backward induction.

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[7] We assume that technology transfer is verifiable and contractible when the licensor can transfer it to the licensee for free.

[8] We first consider a case with only one licensor that will provide a free licensing contract to the only rival firm. Later, we further consider an open technology where the licensor opens the advanced technology so that both rival firms can produce outputs efficiently.

[9] The timing of the game where the government moves after observing the licensor's decision of free licensing indicates the possibilities of flexible privatization. For more discussion, see Haraguchi and Matsumura (2020b).

3. Foreign licensing

In this section, we examine the foreign licensor's decision and compare the equilibrium outcomes between the no licensing and free licensing strategies. In this case, foreign firm 2 has $k_2 = k$, while both firm 0 and firm 1 have $k_j = 1$ (j $\neq 2$) under no licensing, while firm 2 can provide free licensing to domestic firm 1, which results in $k_1 = k_2 = k < k_0 = k$.

In the last stage, each firm simultaneously chooses its output to maximize its objective equation (4), (5), and (6). We provide the equilibrium outcomes of the last stage in Appendix A. Below, we will examine and compare the no licensing and free licensing cases.

3.1 No licensing

When the advanced technology is not transferred to its rival firm, the foreign firm is the only efficient firm; that is, the domestic firm is inefficient. The cost conditions become $k_0 = k_1 = 1 > k_2 = k$. We can set them in the equilibrium outcomes in Appendix A. Then, in the second stage, the government decides the degree of privatization under no licensing to maximize the social welfare in (A5):

$$\theta^{NF} = \frac{26-8\beta+4k(5+2k+(2-\beta)\beta)}{71-8\beta+4k(32+(8-\beta)\beta+k(11+12\beta))}, \qquad (7)$$

where the superscript NF indicates "no licensing with the foreign licensor". Then, we have the following Lemma:[10]

Lemma 1. With a foreign licensor, the optimal degree of privatization under no licensing is partial; that is, $\theta^{NF} \in (0,1)$, which is decreasing in β and k; that is, $\frac{\partial\theta^{NF}}{\partial\beta} < 0$ and $\frac{\partial\theta^{NF}}{\partial k} < 0$.

It states that either higher foreign ownership or a smaller cost gap can increase the flexible degree of privatization without licensing by a foreign licensor.[11]

We summarise the equilibrium outcomes under no licensing of foreign licensor in Table 1.

<Table 1 Equilibrium results under no licensing of foreign licensor>

[10] Appendix C provides some proofs of Lemmas and Propositions. We omit unnecessary proofs because the results require only simple calculations.

[11] Wang and Chen (2011) demonstrate that the government should increase the degree of privatization when the equity share held by the foreign investor is increasing, which increases the profit of all private domestic enterprises and domestic social welfare.

3.2 Free licensing

When the advanced technology is transferred to its rival firm, both the foreign and domestic private firms can use the same efficient technology. The cost conditions become $k_0 = 1 > k_1 = k_2 = k$. We can set them in the equilibrium outcomes in Appendix A. Then, in the second stage, the government decides the degree of privatization under free licensing to maximize the social welfare in (A5):

$$\theta^{FF} = \frac{2(3+12k+12k^2-2\beta-2k\beta+4k^2\beta-2k\beta^2)}{9+50k+96k^2+72k^3+16k^4-2\beta+10k\beta+40k^2\beta+24k^3\beta-4k\beta^2}, \qquad (8)$$

where the superscript FF indicates "free licensing by the public licensor".

Lemma 2. With a foreign licensor, the optimal degree of privatization under free licensing is partial; that is, $\theta^{FF} \in (0,1)$, which is decreasing in β and k; that is, $\frac{\partial \theta^{FF}}{\partial \beta} < 0$ and $\frac{\partial \theta^{FF}}{\partial k} < 0$.

It states that either higher foreign ownership or a lower cost gap can increase the flexible degree of privatization with free licensing by a foreign licensor.

We provide the equilibrium outcomes under free licensing to the foreign licensor in Table 2

<Table 2 Equilibrium results under free licensing of foreign licensor>

3.3. Comparisons

We compare the equilibrium outcomes between no licensing and free licensing.

Proposition 1. With a foreign licensor, the optimal degree of privatization under free licensing is always higher than that under no licensing; that is, $\theta^{FF} > \theta^{NF}$.

This is because the domestic private firm becomes efficient under free licensing and the lower cost can accelerate competition and improve efficiency in the market. Additionally, as the outputs are strategic substitutes, the public firm can be less aggressive and produce lower outputs, which can save the total production cost of the public firm. Further, if the public firm is more privatized under free licensing, then it might mitigate competition in the product market while an efficient private firm can produce more, and the total production cost of the public firm will reduce further due to the output substitution effect. Thus, technology transfers will enhance privatization, which makes the efficient production by the licensee substitute for the inefficient production by the public firm and improves welfare.

Lemma 3. (i) $q_0^{FF} < q_0^{NF}$, (ii) $q_1^{FF} > q_1^{NF}$, (iii) $q_2^{FF} < q_2^{NF}$ and (iv) $Q^{FF} > Q^{NF}$.

It states that both the public and foreign firms decrease their outputs, but the domestic firm increases its output. However, more privatization induced by free licensing will increase total domestic outputs because the output of a domestic private firm (licensee) is greater than the sum of the reduced output of the public and foreign firms. Thus, in a homogeneous product market, increased total output will lower equilibrium prices and increase consumer surplus.[12]

Lemma 4. $CS^{FF} > CS^{NF}$.

Lemma 5. (i) $\pi_0^{FF} \gtreqless \pi_0^{NF}$, (ii) $\pi_1^{FF} > \pi_1^{NF}$ and (iii) $\pi_2^{FF} < \pi_2^{NF}$.

Lemma 3 states that the licensor and licensee can obtain opposite profits under free licensing. From Lemma 3, since the market price and output decrease, the foreign licensor will lose its own profit under free licensing while the licensee can increase output even though the market price decreases. Since both the inefficient public and efficient foreign firms will reduce output while the efficient licensee can produce more to compensate for the reduced output by the other firms, the output effect dominates the price effect and thus the licensee can increase its own profit. However, free licensing is profitable to the public firm only after privatization, when β is large and k is sufficiently small (See Fig. A3).

Proposition 2. Social welfare under free licensing is always higher than that under no licensing; that is, $W^{FF} > W^{NF}$

Proposition 2 states that social welfare increases under free licensing because the increased degree of privatization can induce larger consumer surplus and higher profit for the domestic licensee, which can dominate the possible reduction in the public firm's profit.

Proposition 3. The foreign firm chooses free licensing when it has high ownership of the licensee, while the required level of ownership decreases as the cost gap increases; that is, $V_2^{FF} \gtreqless V_2^{NF}$ if $\beta \gtreqless \beta_F$ where $\beta_F \equiv \beta(k)$, which satisfies $V_2^{\mathrm{FF}} = V_2^{\mathrm{NF}}$.

[Fig. 1] Foreign firm's objective between no licensing and free licensing

Proposition 3 is represented by Fig. 1., which shows that the higher β the better off the foreign firm is under free licensing. If the foreign firm has a high ownership, then it can recover the licensee's profit through passive ownership, and thus the foreign licensor has more incentive to transfer advanced technology. However, its incentive under free licensing decreases as the technology gap increases because the decreased profit of the licensor is large under a sufficiently large cost gap. Thus, the smaller

[12] Note $CS = Q^2/2$. Then, it is easy to see that $\mathrm{CS}^{\mathrm{FF}} > \mathrm{CS}^{\mathrm{NF}}$ from Lemma 3 (iv) $Q^{FF} > Q^{NF}$.

the technology gap, the more effective it is for a foreign licensor to recover a portion of the licensee's profit, as given β. Otherwise, the foreign licensor chooses free licensing only when β is sufficiently large, as given k.

4. Public licensing

In this section, we consider the public licensors' decision and compare the equilibrium outcomes between no licensing and free licensing. In this case, the public firm has $k_0 = k$, both firm 1 and firm 2 have $k_j = 1$ (j $\neq 0$) under no licensing, and firm 0 can provide free licensing to domestic firm 1, which results in $k_0 = k_1 = k < k_2 = k$. Again, the equilibrium outcomes of the last stage are provided in Appendix A. Below, we examine and compare the no licensing and free licensing cases.

4.1 No licensing

When the advanced technology is not transferred to its rival firm, the public firm is the only efficient firm while the foreign and domestic private firms are inefficient. We can set them in the equilibrium outcomes in Appendix A. Then, in the second stage, the government decides the degree of privatization under no licensing to maximize the social welfare in (A5):

$$\theta^{NP} = \frac{2k(27-2\beta^2)}{2k(15-\beta)(3+2\beta)+9(17+2\beta)}, \tag{9}$$

where the superscript *NP* indicates "no licensing with the public licensor".

Lemma 6. With the public licensor, the optimal degree of privatization under no licensing is partial; that is, $\theta^{NP} \in (0,1)$, which is decreasing in β and k; that is, $\frac{\partial\theta^{NP}}{\partial\beta} < 0$ and $\frac{\partial\theta^{NP}}{\partial k} > 0$.

It states that both higher foreign ownership and a higher cost gap can increase the flexible degree of privatization without licensing by a public licensor. Note that in contrast to foreign licensing, the optimal degree of privatization is increasing in the cost gap under public licensing.

We present the equilibrium outcomes under no free licensing by the public licensor in Table 3.

<Table 3 Equilibrium results under no free licensing of public licensor>

4.2 Free licensing

When the advanced technology is transferred to its rival firm, both foreign and domestic private firms can use the same efficient technology. The cost conditions become $k_0 = k_1 = k < k_2 = 1$. We can set them in the equilibrium outcomes in Appendix A. Then, in the second stage, the government decides the degree of privatization under no licensing to maximize the social welfare in (A5):

$$\theta^{FP} = \frac{2k(13+4k^2-2\beta(1+\beta)+2k(5+\beta))}{3(5+4\beta)+4k(23+8k^2+(8-\beta)\beta+k(26+7\beta))}, \tag{10}$$

where the superscript FP indicates "free licensing by the public licensor".

Lemma 7. With the public licensor, the optimal degree of privatization under free licensing is partial; that is, $\theta^{FP} \in (0,1)$, which is decreasing in β but increasing in k; that is, $\frac{\partial\theta^{FP}}{\partial\beta} < 0$ and $\frac{\partial\theta^{FP}}{\partial k} > 0$.

It states that both higher foreign ownership and a higher cost gap can increase the flexible degree of privatization with free licensing by a public licensor. Note that in contrast to foreign licensing, the optimal degree of privatization is increasing in the cost gap under public licensing.

We report the equilibrium outcomes under free licensing by the public licensor in Table 4.

<Table 4 Equilibrium results under free licensing of public licensor>

4.3 Comparisons

We now compare the equilibrium outcomes between no licensing and free licensing.

Proposition 4. With a public licensing contract, the optimal degree of privatization under free licensing is always higher than that under no licensing; that is, $\theta^{FP} > \theta^{NP}$

The economic explanation is the same as for Proposition 1. The domestic private firm becomes efficient under free licensing and this cost efficiency can accelerate competition in the market. Because the public firm produces less output, the total production cost of the public firm also declines. If the public firm is more privatized under free licensing, then an efficient private firm can produce more and the total production cost of the public firm will reduce further. Thus, technology transfers will enhance privatization, which will increase welfare.

Lemma 8 (i) $q_0^{FP} < q_0^{NP}$, (ii) $q_1^{FP} > q_1^{NP}$, (iii) $q_2^{FP} \gtreqless q_2^{NP}$ and (iv) $Q^{FP} \gtreqless Q^{NP}$.

It states that the public firm decreases its outputs while the domestic firm increases its output. However, the foreign firm's output depends on β and k. In particular, Fig. A6 shows that it can increase the output under free licensing when both β and k are sufficiently small. This is because the public firm will be more privatized, which increases the output of not only the domestic licensee but the foreign firm due to the output substitution effect. Fig. A6 also shows that the total industry outputs under free licensing can increase when either β is large or k is large. This is because the output increase by the domestic licensee outweighs the decreased output of the public and foreign firms. It also implies that the market price and consumer surplus also depend on foreign ownership and the technological gap. The change in total industry output exactly implies the change in consumer surplus, as Fig. A7 shows.

Lemma 9. $CS^{FP} \gtreqless CS^{NP}$.

Lemma 9 states that consumer surplus increases under free licensing unless both β and k are small.

Lemma 10. (i) $\pi_0^{FP} \gtreqless \pi_0^{NP}$, (ii) $\pi_1^{FP} > \pi_1^{NP}$ and (iii) $\pi_2^{FP} \gtreqless \pi_2^{NP}$.

Lemma 10 states that the domestic licensee can increase its profit from free licensing while the profits of the rival firms depend on β and k. In particular, Fig. A8 shows that both firms can increase their profits under free licensing when both β and k are small. This is because the public firm will be more privatized, which decreases its output while increasing the output of both the domestic licensee and the foreign firm. From Lemma 8, since the market price increases, the domestic licensee and foreign firm will obtain higher profit under free licensing when both β and k are small. On the other hand, the public licensee decreases its output, but the market price effect dominates the output effect and thus the public licensor can also increase its own profit when both β and k are small. However, free licensing is profitable to the domestic licensee only when either β is large or k is large.

From Lemmas 9 and 10, we can see a trade-off between consumer surplus and the profit of the public firm. In particular, consumer surplus increases while the public firm's profit decreases under free licensing when either β is large or k is large, and vice versa otherwise.

Proposition 5. Social welfare under free licensing is always higher than that under no licensing; that is, $W^{FP} > W^{NP}$.

This proposition indicates that social welfare increases under free licensing because the higher degree of privatization can induce higher profit for the domestic licensee while there is a trade-off between increased (decreased) consumer surplus and decreased (increased) profit for the public firm.

Proposition 6 The public firm chooses free licensing when the technology gap is small and the required level of technology gap is non-monotone in the foreign ownership of the licensee; that is, $V_0^{FP} \gtreqless V_0^{NP}$ if $\beta \gtreqless \beta_P$, where $\beta_P \equiv \beta(k)$, which satisfies $V_0^{\mathrm{FP}} = V_0^{\mathrm{NP}}$.

[Fig. 2] Public licensors objective between free licensing and no free licensing

Proposition 6 is represented by Fig. 2, which shows that that the higher the value of k, the better the public firm is under free licensing. It implies that if the cost gap is small, then free licensing improves welfare but decreases profit. Because the increased degree of privatization is small in that case, the increased welfare outweighs the decreased profit. Note that the incentive for free licensing by the public firm is not significantly affected by β unless β is sufficiently large. However, the public licensor will not transfer technology, even if there is a small technological gap, if β is sufficiently large. This is because all the higher profit will flow out to the foreign firm. Note also that the incentive for free licensing decreases as the technology gap increases; that is, when k is close to 0, because the public should care more about welfare under a low degree of privatization in that case, but consumer surplus decreases when the cost gap is sufficiently large.

5. Discussions

5.1 Comparison between foreign and public licensing contracts

We can first compare the licensor's incentives for free licensing from Proposition 3 and 6. Specifically, from Fig. 1 and Fig. 2, we can identify four different regions from the comparisons of the licensor's objective. In Fig. 3, the bold black line represents the threshold of the foreign licensing, while the dotted red line represents the threshold of public licensing.

Fig. 3 demonstrates that the licensor's choice of free licensing depends crucially on the correlations between the foreign ownership share and technology efficiency gap. If β and k have positive correlations, in particular, then the foreign licensor and public licensor have no licensing in case 2, where both β and k are small enough, and free licensing in case 3, where both β and k are large enough. However, if β and k have negative correlations, then the licensor's incentives for free licensing differ. In particular, the public firm does not transfer technology in case 1, where β is large but k is small, while the foreign firm does not transfer technology in case 4, where β is small but k is large. However, from the welfare perspective, free licensing can always improve welfare.

[Fig.3] Comparisons between foreign and public licensing contracts

Proposition 7. If both β and k are large (small) enough, then the licensor always (never) chooses free licensing under foreign and public licensing contracts.

From these findings, we can provide a few policy suggestions regarding free licensing contracts. First, if β is large but k is small, and thus the technology gap is large (Case 1 where the public firm does not transfer technology, but the foreign firm does), then the government should monitor the free licensing decision of the public firm before privatization. Second, if β is small but k is large, and thus foreign ownership is low (Case 4 where the foreign firm does not transfer technology, but the public firm does), then the government may allow the foreign firm to obtain a higher portion of the shares of domestic firms under passive ownership (if it does not affect anticompetitive behaviours of the foreign firm). Finally, if both β and k are small (Case 2 where both the public and foreign firms do not transfer technology), then it should encourage free licensing contracts before privatization.

5.2 Open technology

We now consider the open technology case in which the licensor transfers advanced technology to all firms in the market. Under both foreign and public licensing, the cost conditions become $k_0 = k_1 = k_2 = k < 1$. We can set them in the equilibrium outcomes in Appendix A. Then, in the second stage, the government decides the degree of privatization under no licensing to maximize the social welfare in (A5):

$$\theta^{\mathrm{OT}} = \frac{2k(3-2\beta+2k(2+2k-\beta)(3+\beta))}{3+4k(7+k(21+8k(3+k)+4\beta+2k(5+2k)\beta-\beta^2))}, \tag{11}$$

where the superscript OT indicates "open technology by the licensor".

Lemma 11. The optimal degree of privatization under open technology is partial; that is, $\theta^{OT} \in (0,1)$, which is decreasing in β but increasing in k; that is, $\frac{\partial\theta^{OT}}{\partial\beta} < 0$ and $\frac{\partial\theta^{OT}}{\partial k} > 0$.

It states that higher foreign ownership or a higher cost gap can increase the flexible degree of privatization under open technology. Note that like public licensing, the optimal degree of privatization is increasing in the cost gap under open technology.

We present the equilibrium outcomes under open technology in Table 5.

<Table 5 Equilibrium results under open technology>

Proposition 8. The optimal degree of privatization under open technology is the lowest (highest) under a foreign (public) licensing contract; that is, $\theta^{\mathrm{FF}} > \theta^{\mathrm{NF}} > \theta^{\mathrm{OT}} > \theta^{\mathrm{FP}} > \theta^{\mathrm{NP}}$.

Proposition 8 shows an interesting finding that open technology yields different incentives for privatization for the government. The case with a foreign licensor, where the public firm can be efficient, should have the lowest optimal degree of privatization because the welfare-oriented public firm is desirable to society from the viewpoint of welfare. The case with a public licensor, however, where the foreign firm can be an efficient rival, should have the highest optimal degree of privatization because the higher competition with more privatized firms can increase total industry output and improve welfare.[13]

Finally, we examine the incentive for open technology for the public and foreign licensors, respectively, and compare the welfare consequences. First, we consider the incentive of the foreign licensor and compare the welfare outcomes.

Proposition 9. The foreign firm will not choose open technology while the welfare is higher under open technology; that is, (i) $V_2^{\mathrm{NF}} > V_2^{\mathrm{OT}}$ and $V_2^{\mathrm{FF}} > V_2^{\mathrm{OT}}$, while (ii) $W^{\mathrm{OT}} > W^{\mathrm{FF}} > W^{NF}$..

This implies that open technology is not an option for the foreign firm, while that is always socially desirable for society. It is therefore necessary for the government to induce the foreign licensor to implement open technology when it enters market.

Second, we consider the incentive of the public licensor and compare the welfare outcomes.

Proposition 10. The public firm will not choose open technology while welfare can be higher under open technology; that is, (i) $V_0^{FP} > V_0^{OT}$, while (ii) $W^{OT} \gtrless W^{FP}$ and $W^{OT} > W^{NP}$.

This implies that open technology is not an option for the public firm. Without considering open technology, from Propositions 5 and 6, we show that the public firm chooses free licensing only when the technology gap is small, but free licensing is always welfare-improving. Proposition 10 (i) also states that even with open technology, the public firm's optimal choice is the same. However, Proposition 10 (ii) is represented by Fig. A11, which shows that free licensing is socially desirable only when both β and k are small, while open technology is otherwise. Therefore, the government must regulate the public licensor to adopt open technology rather than free licensing, except when both β and k are small.

6. Concluding remarks

We investigated and compared free licensing strategies by a foreign and public licensor, respectively, under the flexible choice of privatization policy in a mixed oligopoly in which a public firm competes with two private domestic and foreign firms under passive ownership. We showed that when the licensor transfers its advanced technology to the domestic firm, the licensee's production cost reduction accelerates competition in the production market, which induces the government to increase the degree

[13] We can show that $q_0^{\mathrm{OT}} \gtrless q_0^{\mathrm{FP}}$, $q_1^{\mathrm{OT}} < q_1^{\mathrm{FP}}$, $q_2^{\mathrm{OT}} > q_2^{\mathrm{FP}}$ and $Q^{\mathrm{OT}} > Q^{\mathrm{FP}}$, which implies that more privatization can increase consumer surplus under open technology. On this point, De Fraja and Delbono (1989) also show that more competition with privatization improves welfare.

of privatization. Consequently, free licensing can increase the domestic private firm's profit and welfare, but the incentive for free licensing differs for the foreign licensor and the public licensor.

We showed that with a foreign licensor, the free licensing strategy can be chosen only when the foreign ownership share of the licensee is high, but the required ownership share increases as the efficiency gap between the licensor and licensee increases. Therefore, with a significant amount of foreign ownership, the easing of privatization induced by free licensing will increase social welfare. However, with a public licensor, free licensing can be chosen only when the cost gap is relatively low, irrespective of foreign ownership share.

We further showed that the optimal degree of privatization under a foreign licensor is always higher than that under a public licensor. This finding implies that a foreign licensor creates more motivations for privatization, but state-owned enterprises may act as implicit industrial policies. Such policies aim to extract advanced technologies from foreign firms to improve the productivity of domestic firms or to prevent the outflow of domestic capital to foreign countries by improving the productivity of domestic firms.

Finally, we examined open technology, where all firms in the market have the same technology and found a contrasting result: the optimal degree of privatization under open technology is the lowest (highest) under foreign (public) licensing contracts. However, neither the foreign nor public licensors adopt open technology, even if it may be socially desirable. It is therefore necessary for the government to induce the licensor to adopt open technology under certain regulations.

As future research, we can extend the model with more general forms such as differentiated products, different market structures, and heterogenous objective functions for the firms. Additionally, future studies could examine the robustness of the findings.

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Appendix A: The equilibrium outcomes of the last stage

Each firm simultaneously chooses its output to maximize its objective equation (4), (5) and (6). The first order conditions are as follows:

$$\frac{\partial V_0}{\partial q_0} = a - (1 + \theta + 2k_0)q_0 - (1 - \beta + \beta\theta)q_1 - \theta q_2 = 0$$

$$\frac{\partial V_1}{\partial q_1} = (1 - \beta)(a - q_0 - 2(1 + k_1)q_1 - q_2) = 0 \qquad \text{(A1)}$$

$$\frac{\partial V_2}{\partial q_2} = a - q_0 - (1 + \beta)q_1 - 2(1 + k_2)q_2 = 0$$

Then, we obtain the following equilibrium output levels.[14]

$$q_0 = \frac{a(2-\theta)(1+2k_1)+2a(1+\beta-\beta\theta+2k_1)k_2}{2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))},$$

$$q_1 = \frac{a(\theta+2k_0)(1+2k_2)}{2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))}$$

$$q_2 = \frac{a(\theta+2k_0)(1-\beta+2k_1)}{2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))} \qquad \text{(A2)}$$

$$Q = \frac{a(2+(1-\beta)\theta+2k_0(2-\beta+2k_1+2k_2)+2(1+\beta+(1-\beta)\theta)k_2+4k_1(1+k_2))}{2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))}$$

Substituting the equilibrium outcomes yields the following results.

$$\pi_0 = \frac{a^2((2-\theta)(1+2k_1)+2(1+\beta-\beta\theta+2k_1)k_2)(\theta(1+k_0)(1+2k_1)+2(\theta+(1-\beta(1-\theta))k_0+2(\theta+k_0)k_1)k_2)}{(2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2}$$

$$\pi_1 = \frac{a^2(\theta+2k_0)^2(1+k_1)(1+2k_2)^2}{(2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \qquad \text{(A3)}$$

$$\pi_2 = \frac{a^2(\theta+2k_0)^2(1-\beta+2k_1)(1+(1+\beta)k_2+2k_1(1+k_2))}{(2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2}$$

The consumer surplus social welfare can be obtained as follows.

$$CS = \frac{a^2(2+(1-\beta)\theta+2k_0(2-\beta+2k_1+2k_2)+2(1+\beta+(1-\beta)\theta)k_2+4k_1(1+k_2))^2}{2(2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \qquad \text{(A4)}$$

$$W = \frac{\begin{gathered}a^2(212+(116-31\theta)\theta+\beta^2(2+\theta)^2-6\beta(2+\theta)(6+\theta)+4k(104-2\beta(9+\beta)+62\theta-(21-\beta)\beta\theta-(4+(15-\beta)\beta)\theta^2)\\+4k^2(59-\beta^2(1-\theta)^2-6\beta(1+\theta)(1+2\theta)+\theta(44+5\theta)))\end{gathered}}{2(2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \qquad \text{(A5)}$$

[14] Note that $q_i > 0$ $(i = 0, 1, 2)$ for any k_i and β in [0, 1], and the second-order conditions are satisfied.

The objectives of each firm are as follows.

$$V_0 = \frac{A_1}{2(2+2\theta-\beta\theta+2(1+\beta+2\theta-\beta\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2)))^2}$$

$$V_1 = \frac{a^2(1-\beta)(\theta+2k_0)^2(1+k_1)(1+2k_2)^2}{2(2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \tag{A6}$$

$$V_2 = \frac{a^2(\theta+2k_0)^2(1+k_2+(k_1+\beta k_2)(4-\beta+4k_2+4k_1(1+k_2)))}{2(2+(2-\beta)\theta+2(1+\beta+(2-\beta)\theta)k_2+2k_1(2+\theta+2(1+\theta)k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2}$$

where $A_1 = a^2(4+\theta(4-4\beta-(3-\beta^2)\theta-(3-\beta)(1-\beta)\theta^2)+2k_1\big(8+\theta\big(4-\beta(1-\theta)(4+\theta)-\theta(7+\theta)\big)+4(2-\theta^2)k_1\big)+8k_2+4\Big((1-\theta)(2\beta+(4-\beta-\beta^2)\theta+(3-\beta)(1-\beta)\theta^2)+2k_1\big(4+(1-\theta)\theta(5+\theta)-\beta\big(2-\theta(4-\theta-\theta^2)\big)-2(2-\theta)(1+\theta)k_1\big)\Big)k_2+4\big(1+\beta^2(1-\theta)^3+2\beta(1-\theta)^2(1+2\theta)+\theta(3+\theta-3\theta^2)+2k_1(2+\beta(1-\theta)(2-\theta^2)+\theta(4-\theta-\theta^2)+2(1+\theta)k_1)\big)k_2^2+4(1-\theta)k_0^2\Big(6-(6-\beta)\beta+4k_1^2+4k_2(4-3\beta+(3-2\beta)k_2)+2k_1\big(5-3\beta-4k_2(2-\beta+(1-\beta)k_2)\big)\Big)+2k_0\Big(8-4\beta+2(1-(3-\beta)\beta)\theta-(9-2(5-\beta)\beta)\theta^2+4k_2(5-\beta^2(1-\theta)^2+(3-7\theta)\theta-7\beta(1-\theta)\theta+(3+2\beta-\beta^2+2(2-(4-\beta)\beta)\theta-(6-(6-\beta)\beta)\theta^2)k_2)+4k_1^2(4-\theta(2+\theta)+4(2-\theta+k_2)k_2)+4k_1\big(6-\theta(2+3\theta)-2\beta(1-\theta^2)+2k_2(7-\beta(1-\theta)(1+2\theta)-\theta(2+3\theta)+2(2-\beta(1-\theta)\theta-\theta^2)k_2)\big)\Big))$

Appendix B: Tables and Figures

[Tables]

Table 1 Equilibrium results under no licensing of foreign licensor

$q_0^{NF} = \frac{a(1+2k)(29-2\beta+k(22+8\beta))}{127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta)}$	$q_1^{NF} = \frac{2a(1+2k)(7+8k-\beta)}{127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta)}$
$q_2^{NF} = \frac{2a(3-\beta)(7+8k-\beta)}{127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta)}$	$Q^{NF} = \frac{a(85+4k(43-4\beta)-2(12-\beta)\beta+4k^2(19+4\beta))}{127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta)}$
$\pi_0^{NF} = \frac{a^2(1+2k)^3(13-4\beta)(29-2\beta+k(22+8\beta))}{(127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta))^2}$	$\pi_1^{NF} = \frac{8a^2(1+2k)^2(7+8k-\beta)^2}{(127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta))^2}$
$\pi_2^{NF} = \frac{4a^2(3-\beta)(7+8k-\beta)^2(3+k(3+\beta))}{(127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta))^2}$	
$V_0^{NF} = \frac{A_2}{(127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta))^2(71-8\beta+4k(32+(8-\beta)\beta+k(11+12\beta)))}$	
$V_1^{NF} = \frac{8a^2(1+2k)^2(1-\beta)(7+8k-\beta)^2}{(127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta))^2}$	$V_2^{NF} = \frac{4a^2(7+8k-\beta)^2(9-\beta+k(9+(8+8k-\beta)\beta))}{(127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta))^2}$
$CS^{NF} = \frac{a^2(85+4k(43-4\beta)-2(12-\beta)\beta+4k^2(19+4\beta))^2}{2(127+4k(76-7\beta)-2(15-\beta)\beta+4k^2(43+4\beta))^2}$	$W^{NF} = \frac{a^2(69+k^2(84-16\beta)+36k(4-\beta)-2(13-\beta)\beta)}{254+8k(76-7\beta)-4(15-\beta)\beta+8k^2(43+4\beta)}$

$A_2 = a^2(1+2k)(413939-4\beta(63789-\beta(13857-(1292-45\beta)\beta))+32k^5(8699+4\beta(2519-4\beta(79+12\beta)))+16k^4(102739+4\beta(14951-\beta(4611+8\beta(11-2\beta))))+16k^3(228223+4\beta(10596-\beta(8868-\beta(665+12\beta))))+8k^2(488311-4\beta(15293+2\beta(5461-3\beta(357-16\beta))))+2k(1016491-4\beta(98275-\beta(2214+\beta(2702-\beta(335-12\beta)))))))$

Table 2 Equilibrium results under free licensing of foreign licensor

$$q_0^{FF} = \frac{a(1+2k)^2(3+2k(5+2k+\beta))}{(1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2} \qquad q_1^{FF} = \frac{2a(1+2k)(3+4k(2+k)-\beta)}{(1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2}$$

$$q_2^{FF} = \frac{2a(1+2k-\beta)(3+4k(2+k)-\beta)}{(1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2} \qquad Q^{FF} = \frac{a((1+2k)^2(15+2k(9+2k))-2(5+11k-4k^3)\beta+2\beta^2)}{(1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2}$$

$$\pi_0^{FF} = \frac{a^2(1+2k)^4(3+6k+4k^2-2(1+k)\beta)(3+2k(5+2k+\beta))}{((1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2)^2} \qquad \pi_1^{FF} = \frac{4a^2(1+k)(1+2k)^2(-3-4k(2+k)+\beta)^2}{((1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2)^2}$$

$$\pi_2^{FF} = \frac{4a^2(1+2k-\beta)(3+4k(2+k)-\beta)^2(1+k(3+2k+\beta))}{((1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2)^2}$$

$$V_0^{FF} = \frac{A_3}{2((1+2k)^2(21+2k(17+6k))+2(1+2k)(-6+k(-3+2k))\beta+2\beta^2)^2(9-2\beta+2k(4k(12+k(9+2k))+4k(5+3k)\beta-2\beta^2+5(5+\beta)))}$$

$$V_1^{FF} = \frac{4a^2(1+k)(1+2k)^2(1-\beta)(3+4k(2+k)-\beta)^2}{((1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2)^2} \qquad V_2^{FF} = \frac{4a^2(3+4k(2+k)-\beta)^2(1+k(5+(3-\beta)\beta+8k(1+\beta)+4k^2(1+\beta)))}{((1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2)^2}$$

$$CS^{FF} = \frac{a^2((1+2k)^2(15+2k(9+2k))-2(5+11k-4k^3)\beta+2\beta^2)^2}{2((1+2k)^2(21+2k(17+6k))-2(1+2k)(6+k(3-2k))\beta+2\beta^2)^2} \qquad W^{FF} = \frac{a^2((1+2k)^2(15+2k(7+2k))-2(1+2k)(6+k(5+2k))\beta+2\beta^2)}{2(1+2k)^2(21+2k(17+6k))-4(1+2k)(6+k(3-2k))\beta+4\beta^2}$$

$$A_3 = (a+2ak)^2((1+2k)^4(1053+2k(3699+4k(1968+k(1907+4k(236+k(59+6k))))))-2(1+2k)^3(405+k(2307+2k(893-2k(537+14k(59+26k+4k^2)))))\beta+8(1+2k)(36+k(256+k(5+2k)(135+65k-12k^3)))\beta^3-4(21+2k(61+2k(53+2k(7-4k(2+k)))))\beta^4+8(1+3k)\beta^5-4(42+k(524+k(2621+2k(2027+4k(339+k(107+14k))))))(\beta+2k\beta)^2)$$

Table 3 Equilibrium results under no free licensing of public licensor

$$q_0^{NP} = \frac{9a(17+2\beta)}{2k(15+\beta)^2+9(17+2\beta)} \qquad q_1^{NP} = \frac{6ak(15-\beta)}{2k(15-\beta)^2+9(17+2\beta)} \qquad q_2^{NP} = \frac{2ak(15-\beta)(3-\beta)}{2k(15-\beta)^2+9(17+2\beta)}$$

$$Q^{NP} = \frac{a(9(17+2\beta)+2k(90-21\beta+\beta^2))}{2k(15-\beta)^2+9(17+2\beta)} \qquad \pi_0^{NP} = \frac{81a^2k(17+2\beta)(13-4\beta)}{(2k(15-\beta)^2+9(17+2\beta))^2} \qquad \pi_1^{NP} = \frac{72a^2k^2(15-\beta)^2}{(2k(15-\beta)^2+9(17+2\beta))^2}$$

$$\pi_2^{NP} = \frac{4a^2k^2(15-\beta)^2(3-\beta)(6+\beta)}{(2k(15-\beta)^2+9(17+2\beta))^2} \qquad V_0^{NP} = \frac{9a^2(18k(15-\beta)(21-2\beta)(17+2\beta)^2+81(17+2\beta)^3+8k^3(15-\beta)^2(2+3\beta)(72-(48-\beta)\beta)+4k^2(15-\beta)(17+2\beta)(1647-\beta(378+\beta(63+\beta))))}{2(2k(15-\beta)(3+2\beta)-9(17+2\beta))(2k(15-\beta)^2+9(17+2\beta))^2}$$

$$V_1^{NP} = \frac{72a^2k^2(15-\beta)^2(1-\beta)}{(2k(-15+\beta)^2+9(17+2\beta))^2} \qquad V_2^{NP} = \frac{4a^2k^2(15-\beta)^2(18+(15-\beta)\beta)}{(2k(15-\beta)^2+9(17+2\beta))^2} \qquad CS^{NP} = \frac{a^2(2k(15-\beta)(6-\beta)+9(17+2\beta))^2}{2(2k(15-\beta)^2+9(17+2\beta))^2}$$

$$W^{NP} = \frac{a^2(9(17+2\beta)+2k(72-(48-\beta)\beta))}{306+4k(15-\beta)^2+36\beta}$$

Table 4 Equilibrium results under free licensing of public licensor

$$q_0^{FP} = \frac{3a(5+4\beta+2k(13+10k+\beta))}{3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta)} \qquad q_1^{FP} = \frac{6ak(7+8k-\beta)}{3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta)}$$

$$q_2^{FP} = \frac{2ak(1+2k-\beta)(7+8k-\beta)}{3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta)} \qquad Q^{FP} = \frac{a(3(5+4\beta)+2k(67+16k^2+k(76-10\beta)-(8-\beta)\beta))}{3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta)}$$

$$\pi_0^{FP} = \frac{27a^2k(3+6k+4k^2-2(1+k)\beta)(5+4\beta+2k(13+10k+\beta))}{(3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta))^2} \qquad \pi_1^{FP} = \frac{36a^2k^2(1+k)(7+8k-\beta)^2}{\left(3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta)\right)^2}$$

$$\pi_2^{FP} = \frac{4a^2k^2(1+2k-\beta)(7+8k-\beta)^2(2+4k+\beta)}{(3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta))^2}$$

$$V_0^{FP} = \frac{A_4}{2\left(3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta)\right)^2(3(5+4\beta)+4k(23+8k^2+(8-\beta)\beta+k(26+7\beta)))}$$

$$V_1^{FP} = \frac{36a^2k^2(1+k)(1-+\beta)(7+8k-\beta)^2}{(3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta))^2} \qquad V_2^{FP} = \frac{4a^2k^2(7+8k-\beta)^2(2+8k(1+k)+8\beta+7k\beta-\beta^2)}{(3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta))^2}$$

$$CS^{FP} = \frac{a^2(3(5+4\beta)+2k(67+16k^2+k(76-10\beta)-(8-\beta)\beta))^2}{2(3(5+4\beta)+2k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta))^2} \qquad W^{FP} = \frac{a^2(3(5+4\beta)+2k(73+4k(16+k)-23\beta-22k\beta+\beta^2))}{6(5+4\beta)+4k(88+64k^2+2k(71-8\beta)-(11-\beta)\beta)}$$

$$A_4 = 3a^2(8192k^9+1024k^8(185-38\beta)+9(5+4\beta)^3+12k(5+4\beta)^2(97-(8-\beta)\beta)+128k^7(8262-\beta(1433+263\beta))+64k^6(41819-\beta(4813+\beta(2928-191\beta)))+4k^2(5+4\beta)(13948-\beta(46+\beta(306-\beta(38+\beta))))+32k^5(113887-\beta(3000+\beta(12376-\beta(1342-37\beta))))+16k^4(176100-\beta(20971+\beta(24854-\beta(3069-\beta(157-2\beta)))))+8k^3(153052+\beta(56054-\beta(21888-\beta(2015-\beta(113-6\beta))))))$$

Table 5 Equilibrium results under open technology

$$q_0^{OT} = \frac{a(1+2k)^2(3+2k(5+2k+\beta))}{3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2)} \quad q_1^{OT} = \frac{2ak(1+2k)(3+4k(2+k)-\beta)}{3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2)}$$

$$q_2^{OT} = \frac{2ak(1+2k-\beta)(3+4k(2+k)-\beta)}{3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2)} \quad Q^{OT} = \frac{a(3+2k(17+68k^2+24k^3+8k(7-\beta)-(4-\beta)\beta))}{3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2)}$$

$$\pi_0^{OT} = \frac{a^2k(1+2k)^4(3+6k+4k^2-2(1+k)\beta)(3+2k(5+2k+\beta))}{(3+2k(4k\left(19+k\left(29+2k(9+2k)\right)\right)+5(4-\beta)-4k(3+k)\beta+\beta^2))^2} \quad \pi_1^{OT} = \frac{4a^2k^2(1+k)(1+2k)^2(3+4k(2+k)-\beta)^2}{(3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2))^2}$$

$$\pi_2^{OT} = \frac{4a^2k^2(1+2k-\beta)(3+4k(2+k)-\beta)^2(1+k(3+2k+\beta))}{(3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2))^2}$$

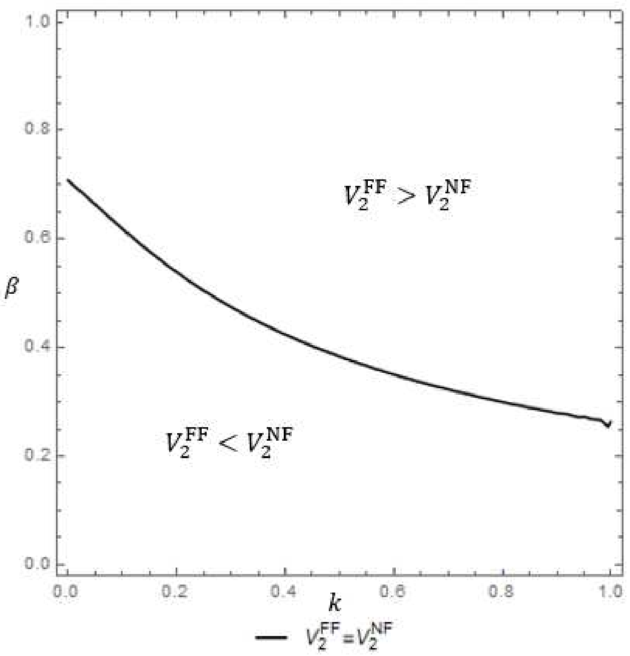
$$V_0^{OT} = \frac{A_5}{(2(3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2))^2(3+4k(7+k(21+8k(3+k)+4\beta+2k(5+2k)\beta-\beta^2))))}$$

$$V_1^{OT} = \frac{4a^2k^2(1+k)(1+2k)^2(1-\beta)(3+4k(2+k)-\beta)^2}{(3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2))^2} \quad V_2^{OT} = \frac{4a^2k^2(3+4k(2+k)-\beta)^2(1+k(5+(3-\beta)\beta+8k(1+\beta)+4k^2(1+\beta)))}{(3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2))^2}$$

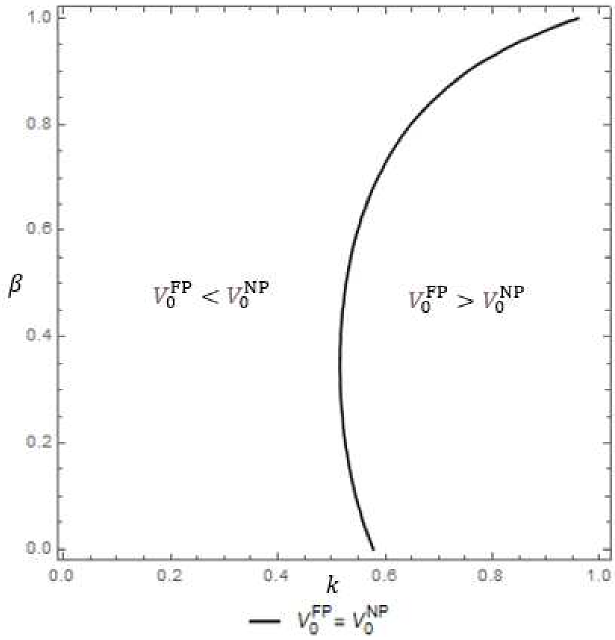
$$CS^{OT} = \frac{a^2(3+2k(17+68k^2+24k^3+8k(7-\beta)-(4-\beta)\beta))^2}{2(3+2k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2))^2} \quad W^{OT} = \frac{a^2(3+2k(17+2k(3+2k)(9+4k)-5\beta-2k(7+6k+4k^2)\beta+\beta^2))}{6+4k(4k(19+k(29+2k(9+2k)))+5(4-\beta)-4k(3+k)\beta+\beta^2)}$$

$A_5 = (a+2ak)^2((1+2k)^4(27+4k(135+k(963+2k(1451+4k(520+k(371+2k(63+8k))))))) - 4k(1+2k)^3(36 - k(411+4k(241+2k(17-2k(86+3k(25+6k))))))\beta - 8k^2(1+2k)^2(9-k(87+2k(103+2k(41+2k(9+2k)))))\beta^3 + 4k^2(1+2k)(3-4k(9+2k(7+2k)))\beta^4 + 16k^3(1+k)\beta^5 + 4k(9+2k(66-k(13+2k(389+2k(413+4k(102+k(63+4k(6+k)))))))))(\beta+2k\beta)^2)$

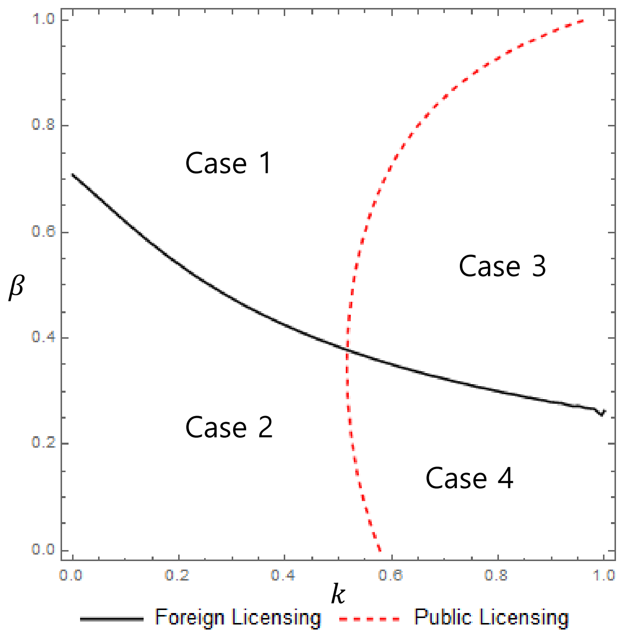
[Figures]



[Fig. 1] Foreign firm's objective between no licensing and free licensing



[Fig. 2] Public licensors objective between free licensing and no free licensing

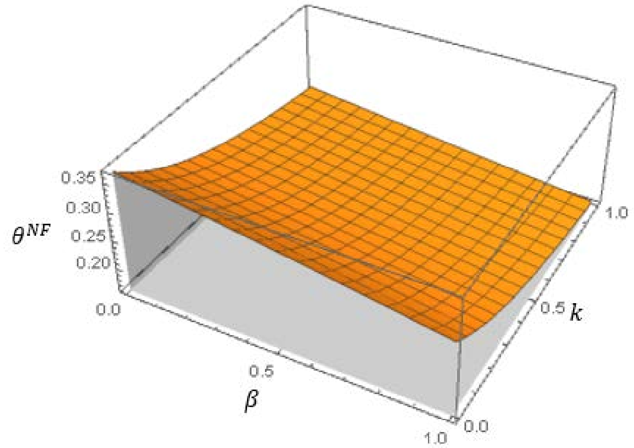


[Fig.3] Comparisons between foreign and public licensing contracts

Appendix C: Proofs of Lemmas and Propositions

The proof of Lemma 1.

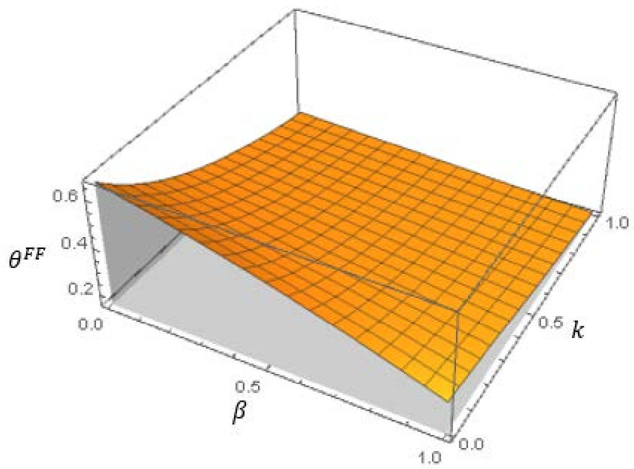
$\theta^{NF} \in [0,1)$ is decreasing in β and k



[Fig. A1] The optimal degree of privatization under no licensing of foreign firm

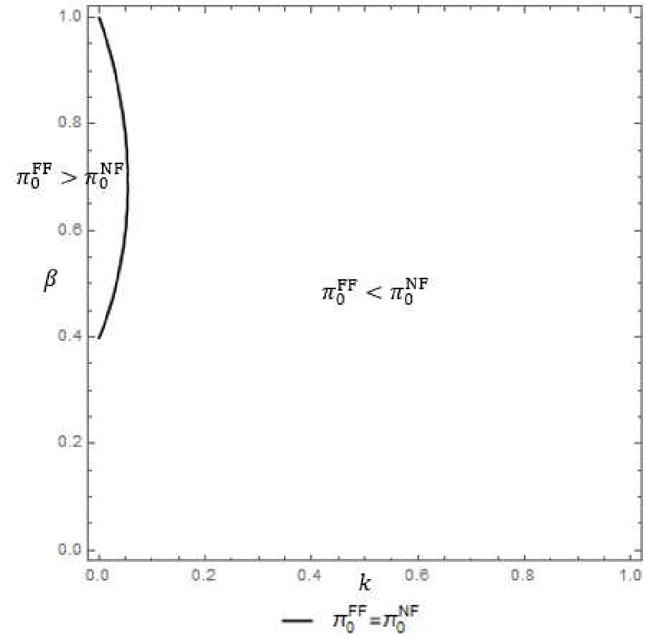
The proof of Lemma 2.

$\theta^{FF} \in [0,1)$ is decreasing in β and k



[Fig. A2] The optimal degree of privatization under no licensing of foreign firm

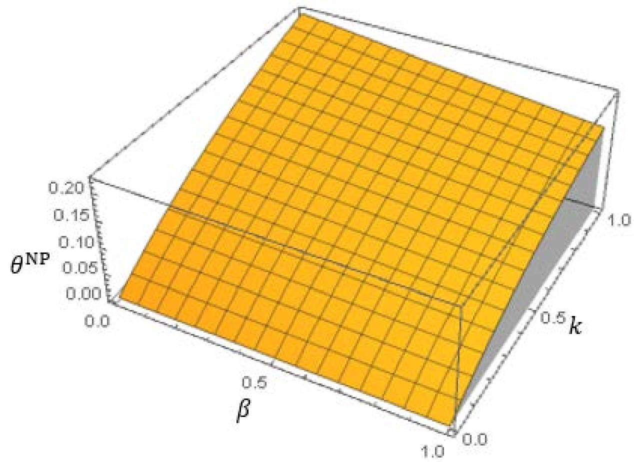
The proof of Lemma 5



[Fig. A3] Public firm's profit between no licensing and free licensing

The proof of Lemma 6.

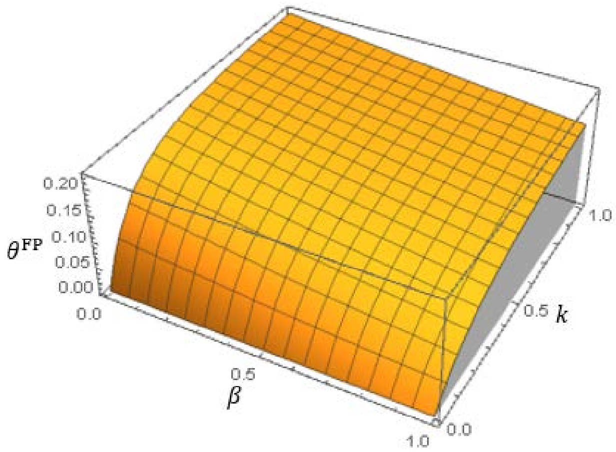
$\theta^{NP} \in [0, 1)$ is decreasing in β but is increasing k



[Fig. A4] The optimal degree of privatization under no licensing of public firm

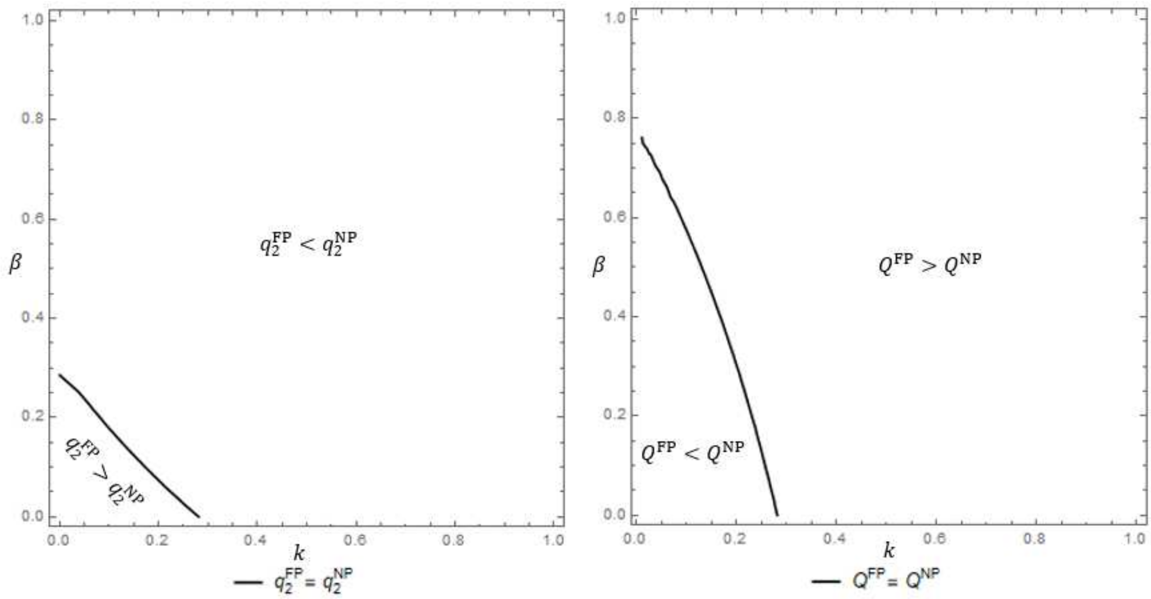
The proof of Lemma 7.

$\theta^{FP} \in [0, 1)$ is decreasing in β but is increasing k



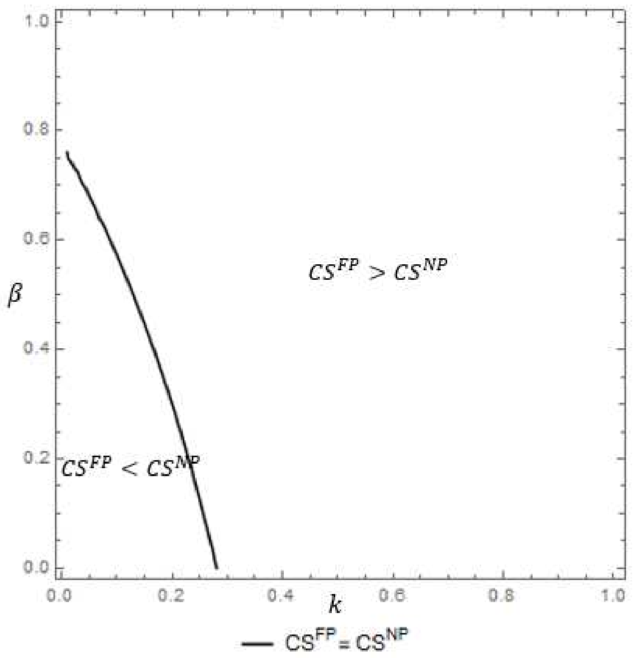
[Fig. A5] The optimal degree of privatization under free licensing of public firm

The proof of Lemma 8. (i)



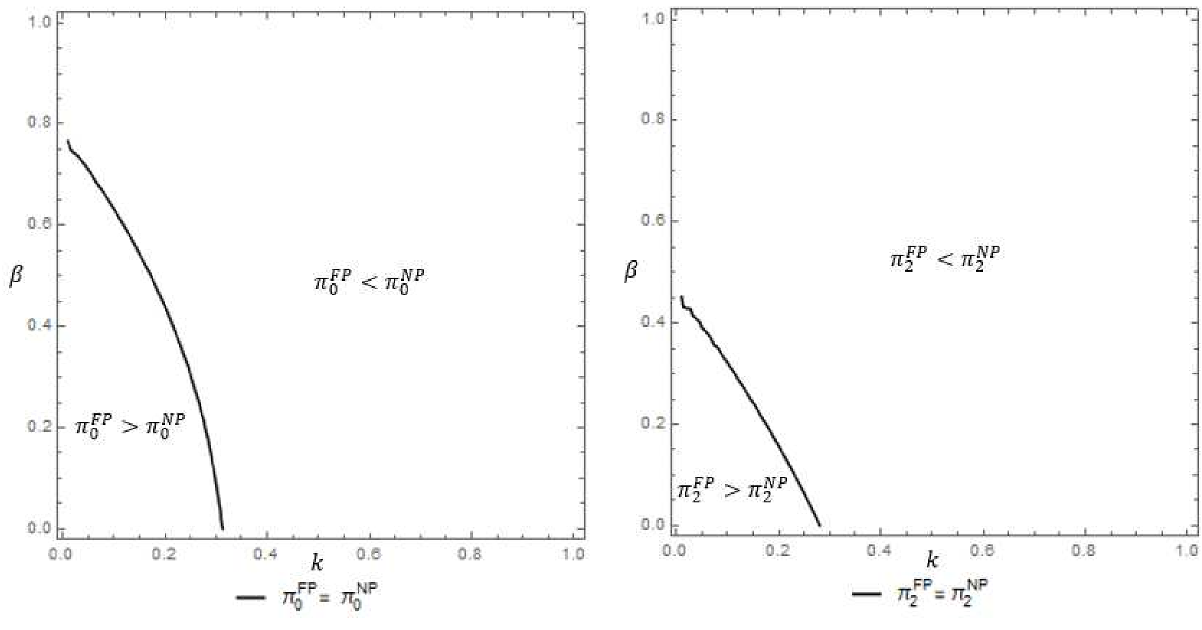
[Fig.A6] Foreign firm's output and domestic total output between no licensing and free licensing

The proof of Lemma 9.



[Fig.A7] Consumer surplus between no licensing and free licensing under public licensing

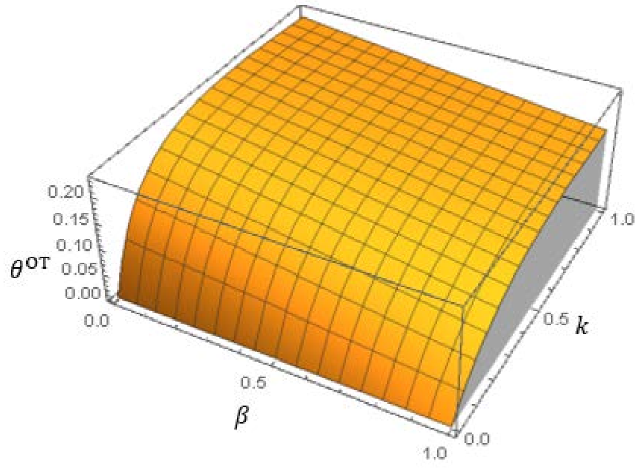
The proof of Lemma10.



[Fig. A8] Public firm's profit and foreign firm's profit between no licensing and free licensing

The proof of Lemma 11.

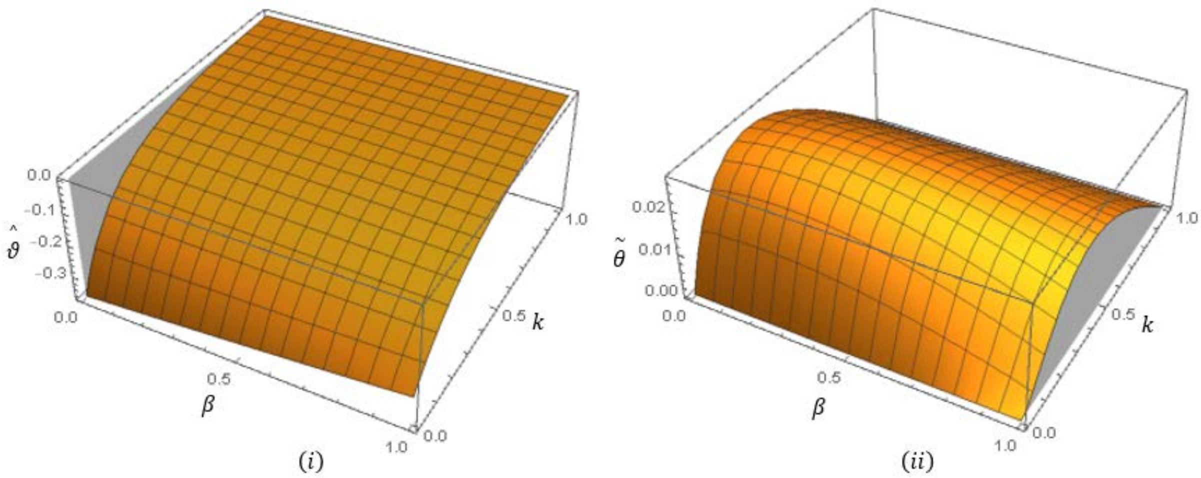
$\theta^{\mathrm{OT}} \in [0,1)$ is decreasing in β but is increasing k



[Fig. A9] The optimal degree of privatization under open technology

Proof of Proposition 8

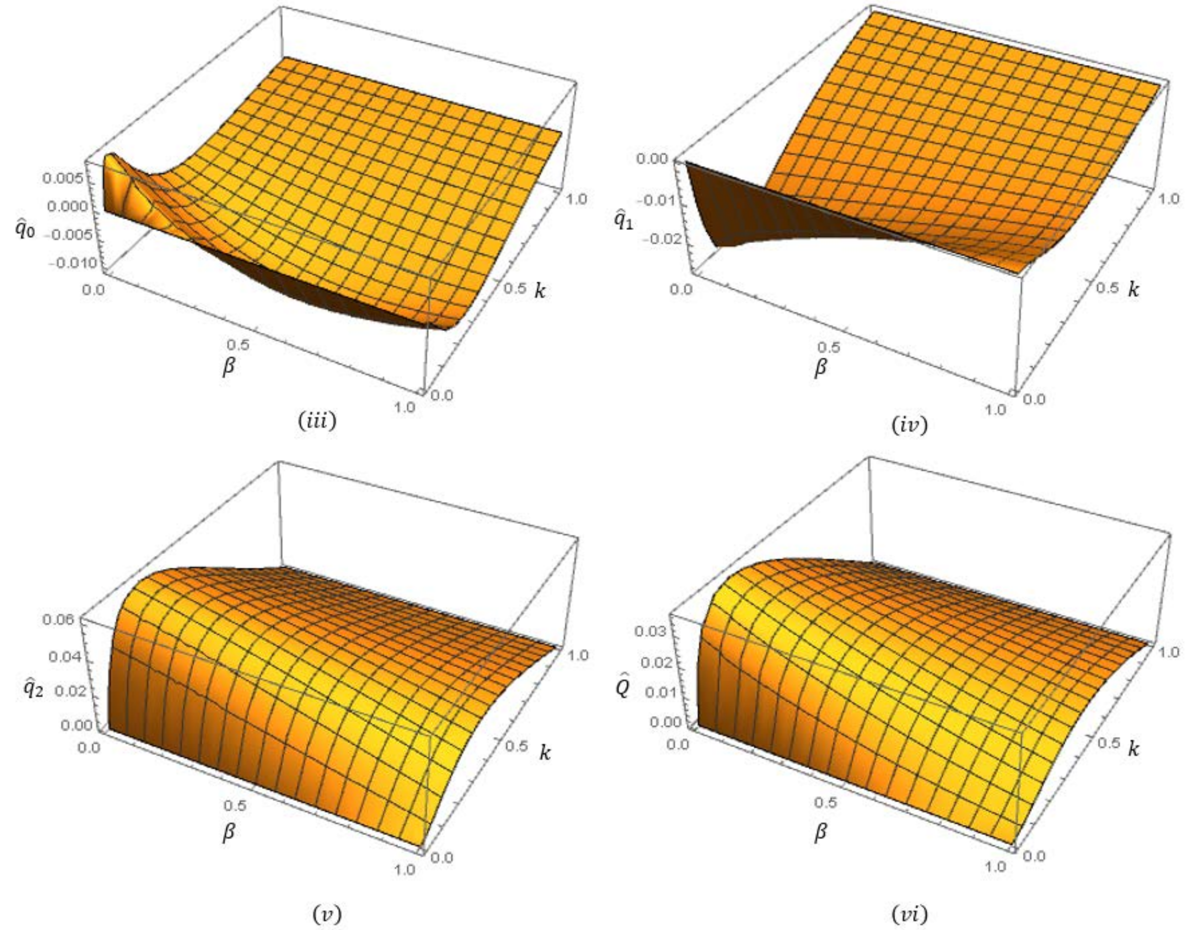
$(i)\ \hat{\vartheta} = \theta^{\mathrm{OT}} - \theta^{\mathrm{NF}} < 0$ and $(ii)\ \tilde{\theta} = \theta^{\mathrm{OT}} - \theta^{\mathrm{FP}} > 0$



(i) (ii)

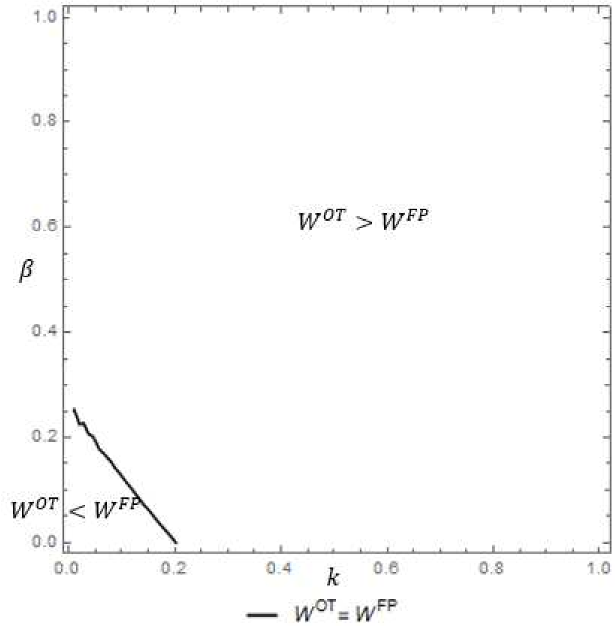
[Fig. A10-1] Comparisons of the optimal degree of privatization

$(iii)\ \hat{q}_0 = q_0^{\mathrm{OT}} - q_0^{\mathrm{FP}} \gtrless 0$, $(iv)\ \hat{q}_1 = q_1^{\mathrm{OT}} - q_1^{\mathrm{FP}} < 0$, $(v)\ \hat{q}_2 = q_2^{\mathrm{OT}} - q_2^{\mathrm{FP}} > 0$, and $(vi)\ \hat{Q} = Q^{\mathrm{OT}} - Q^{\mathrm{FP}} > 0$



[Fig. A10-2] Comparisons of the Output between open technology and public free licensing

Proof of Proposition 10



[Fig. A11] Open technology vs. Public free licensing