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Voluntary Technology Sharing under Partial Passive Ownership and Privatization Policy*

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Abstract When knowledge sharing is non-contractible, we investigate the effect of partial passive ownership (PPO) on the incentive of voluntary technology sharing between rival firms under privatization policy. We show that an efficient private firm chooses technology sharing irrespective of the presence of public firm when it has sufficiently high degree of PPO in the rival firm and this knowledge sharing always increases welfare. We also show that the privatization of public firm might deter voluntary technology sharing and decrease welfare if an efficient private firm has relatively high degree of partial passive ownership while cost gap between the private firms is not large. Finally, we examine a foreign firm's voluntary technology sharing and show that the deterrence effect of privatization policy is less serious than domestic firm but privatization always decreases the welfare.

Keywords Mixed Triopoly, Partial Passive Ownership(PPO), Privatization Policy, Voluntary Technology Sharing

JEL Classification D45, L13, L31, L33

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1. INTRODUCTION

Technological superiority has significant impacts on firms and its rival, which can enhance product competitiveness of a firm and improve its profits. However, some firms share their technologies through technology licensing, technology transfer, and other options, which has become common market behavior[1] Internal or/and external cooperation between the firms through technology sharing has beneficial effects on market performance and thus, technology sharing is an important conduct in many industries.[2] It has been attracted by aair amount of attention in the literature of economics, but the reimbursement mechanism is an important key for understanding the reason of technology sharing.

In the meantime, we observed some stylized facts of product innovation transfer in the technology industry by an innovation firm that has partial passive ownership(PPO) in its rival firms.[3] The followings relate to the steel and automobile industries.[4] First, Japanese Nippon Steel and Korean Pohang Iron held 0.5% ownership stakes in each other in the early '90s and increased to 1% $\sim$3% in the late '90s for a strategic alliance to share technology. Second, Volkswagen possessed a 19.89% stake in Suzuki in 2009 on the purpose of transferring innovative product technology on diesel and hybrid car engines to Suzuki.[5] Finally, Toyota

[1]Technology sharing describes a transfer of technology between two or more firms. There are many forms of technology sharing, among which licensing is the primary method. See Kim and Lee, 2014; Kim and Lee, 2016; Nguyen *et al*., 2017; and Wang *et al*., 2020. Kim (2020) also shows that in vertically integrated markets, the patent holder allows its rivals to use its patent even without a license but keeps the option of patent litigation.

[2]For example, through the acquirement of new knowledge and the updating of existing knowledge, an organization can have better learning and innovation performance and thus develop a sustainable competitive advantage. See Liao and Hu, 2007; Huang and Yu, 2011; and Liao *et al*., 2017.

[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. For more real-world examples, see Farrell and Shapiro, 1990; Cavusgil *et al*., 2003; Liker and Choi, 2004; Li *et al*., 2015; Ghosh and Morita, 2017; Liu *et al*., 2018; Bayona and López, 2018; Papadopoulos *et al*., 2019; Leonardos *et al*., 2021; Fanti and Buccella, 2021 and Cho *et al*., 2022 among others.

[4]Technology transfer also happens between suppliers and buyers in a supply chain. For example, executives and engineers who work for Toyota and for its suppliers meet under the direction of a Toyota sensei (teacher) to improve the suppliers' processes. Similarly, Honda of America sent an engineer to spend a year with a Cleveland-based company, Atlantic Tool and Die. The engineer offered suggestions that led to marked improvements on the shop floors (Liker and Choi, 2004). Furthermore, it does not confide with the automobile industry. For example, in 2010 Monsanto acquired a 19.9% stake in InterGrain, a rival cereal breeder in Australia, for gaining access to superior varieties explicitly based on product innovation transfer (Papadopoulos *et al*., 2019).

[5]However, the VW–Suzuki alliance in 2009 failed in 2011 because "VW would need a 33%

acquired a 5% stake in the Chinese iron and steel company BFS in 2015, and also decided to technology transfer to provide Guangzhou Automobile Group(GAC Group), a Chinese automobile manufacturer, with its gasoline-electric hybrid technology system to expand the market for hybrid cars in China.

Recent works have examined the relationship between technology sharing with fee(or for free) and PPO. Ghosh and Morita (2017), Papadopoulos *et al*. (2019), and Hunold and Shekhar (2022) showed that if a technology(e.g., tacit knowledge) is noncontractible and licensing is not an option, the firm that owns the technology can induce technology transfer for free by acquiring a part of the rival firm. Thus, both licensing and PPO strategies are substitutes. Leonardos *et al*.(2021) further considered contractible technology licensing in a Cournot duopoly and showed that these two strategies can be complementary; that is, PPO can promote fee licensing and increase consumer surplus and welfare.

Other scholars also examine a mixed oligopoly[6] where a public firm competes with private firms and explore the welfare effect of technology sharing strategies. Mukherjee and Sinha (2014) consider cost asymmetry between the public and private firms and show that if technology licensing is transferred, the optimal government policy is full nationalization. In the presence of technology licensing, therefore, cost asymmetry between the firms may not necessarily justify privatization. Wang *et al*. (2020) examine fee licensing contracts from an efficient private firm(or a public firm) to either a public or a private(either domestic or foreign) firms, and demonstrate that licensing to the private firm motivates privatization, whereas licensing to the public firm reduces the incentive for privatization compared with foreign licensing. Haraguchi and Matsumura (2020) examine voluntary technology sharing between domestic and foreign private firms and show that potential future privatization encourages free technology transfers from foreign firms to domestic firms. Cho *et al*. (2022) also consider free technology sharing under PPO between the private firms and investigate the interaction with flexible privatization policy in a mixed oligopoly. They incorporate the foreign share of PPO in domestic firms and show that the incentive of free technology sharing increases when the government can flexibly change its ex-post degree of privatization.

These previous works examined the flexible role of public firms in a time-

stake to ensure smooth technology transfers". See Papadopoulos *et al*.(2019)

[6]In current economy, many public enterprises with significant government ownership are still active in strategic sectors, such as transportation, telecommunications, energy, and finance in OECD countries, and they control a large proportion of the world's resources. For recent discussions, see Huang and Yang, 2016; Chen, 2017; Lee *et al*., 2018; Kim *et al*., 2019; Lee and Muminov, 2021; and Xu, 2021.

consistent framework where the government can change its optimal decision after the efficient firm determines technology transfer.[7] That is, under fee licensing contract, as examined by Mukherjee and Sinha (2014) and Wang *et al*. (2020), if technology licensing is transferred from the efficient private firm, licensing to the public firm reduces the incentive of the government for privatization and thus the optimal government policy is full nationalization. Even if technology licensing is transferred between the private firms, as shown in Haraguchi and Matsumura (2020) and Wang *et al*. (2020), flexible privatization can always increase the welfare since it can induce the efficient firm to transfer its superior technology to an inefficient private firm. This logic can be also applied to free licensing case as far as the efficient firm has a PPO in a mixed triopoly market, as examined by Cho *et al*. (2022).

However, it is often politically difficult for the government to choose flexible policy option especially once it committed to its ex ante policy map and scheduled policy guideline to the public. That is, due to the of nature characteristics of public policy by the government, the ex-ante commitment to the public is more irreversible, compared to the firm-level strategy. In this case, the government should credibly commit to its policy rule and then induce firms to adopt their actions to maximize their objectives under the committed policy framework. In reality, furthermore, the ex-post change in the policy schedule might cause serious social cost among the interest groups. Since privatization policy can change their employment status and wage levels, it's policy schedule can be an important political element to negotiate between the government and the public firm(among employees and public citizens) under the incomplete delegation contract wherein the government cannot perfectly control the managers of the public firm, especially when it is related with the public attention and mass media.[8] However, in the case of (implicit) technology transfer, the strategy can

[7]In the literature of oligopoly theory, time-consistency issue in different timings of firm investment and government policy has been discussed since Laffont and Tirole (1996). For example, **?** and Petrakis and Petrakis (2001) and Poyago-Theotoky and Teerasuwannajak (2002) considered the case that the firm chooses its R&D before the government policy and then induces the government to adjust its flexible policy to be favorable to the firm in a time-consistency framework. Recently, Chen *et al*. (2022) also compares the strategic incentives between the firm and the government under flexible and irreversible investment.

[8]For instance, the Korean government announced plans to privatize its electricity power utility(Korea Electric Power Corporation), which was a government-invested monopolist that supplied electric power in Korea. During 2000s, the Korean electric power industry underwent major changes as its power generation unit was separated into six subsidiaries and the power generation subsidiaries are supposed to be privatized, and it is preparing separate power distribution units. However, there were many debates between the government and employees(or even the public),

be determined by the executives of the firm who can control the managers of the private firm even though they are under the managerial delegation contract in an organizational context.[9] That is, ex post change of strategy is more flexible than ex post policy change.

Therefore, previous theoretical analysis of an ex post privatization policy might not be simply applied to the real political economy. This also implies that it is also important to examine the commitment effect of privatization policy on the flexible licensing strategy of the firm. Our study bridges some possible explanations on the licensing strategy between the private firms and highlight the importance of the public commitment by the government.

In this paper, we adopt the model in Cho *et al*. (2022) where a technology (e.g., tacit knowledge) is noncontractible and thus technology sharing through fee licensing is not an option, but the efficient firm has a PPO of the rival firm and obtain a part of operating profit of the rival firm through free technology transfer. However, contrary to Cho *et al*. (2022) in which the privatization policy by the government is made after the choice of technology transfer, we consider the case when the choice of voluntary technology transfer occurs after the committed privatization policy. In addition, given the committed privatization and nationalization policy regimes, we compare the welfare effects of privatization policy on the incentives of transfer technology when the efficient firm which has PPO in its rival private firm is either a domestic firm or a foreign one. We emphasize that the committed privatization policy can play an important role in determining the incentive of technology sharing. We show that an efficient firm in both private and mixed markets chooses technology sharing with its rival private firm when it has sufficiently high degree of PPO in the rival firm, which always increases welfare. We also show that privatization policy might deter voluntary technology sharing and decrease welfare if an efficient firm has relatively high degree of PPO in the rival firm and the cost gap between the private firms is not large. We also consider an efficient foreign firm and show that the deterrence effect of privatization is less serious, but privatization always decrease the welfare.

The economic reason is as follows: Let's consider that the government can commit to the nationalization of public firm. Then, an efficient licensor can expect that technology sharing strategy can induce the public firm to take a less

which causes ongoing social costs in both the privatization and separation processes. See Lee (2006) for more detailed discussion.

[9] According to incomplete contract theory, it is well-known that in an organization structure of the firm, both control and monitor are of nature characteristic of the firm to resolve the conflicts between the owners and the managers or employees. See some selective works in Williamson (1996).

aggressive action in providing the goods since private firms can more efficiently substitute the production of the public firm, which will decrease social production cost. Thus, an efficient firm is willing to choose ex post technology sharing if the level of PPO is sufficiently high, which can reimburse the increased profit of the licensed firm to the licensor. However, if the government can commit to the privatization of public firm, the incentive of license is weakened since the profit-maximizing privatized firm is already less aggressive in providing the goods. Thus, an efficient firm is less willing to choose ex post technology sharing under privatization policy, compared to nationalization policy, even though the level of PPO is sufficiently high. Therefore, when the technology sharing between the private firms is forthcoming, it might not be an ex ante optimal choice of the government to implement privatization policy.

The remaining of the paper is organized as follows. Section 2 introduces the basic model. We examine voluntary technology sharing by domestic firm of a mixed and a private market and compare the impact of privatization policy in Sections 3. In Section 4, we show a case that an efficient licensor is a foreign firm. Section 5 concludes.

2. THE BASIC MODEL

We consider a mixed triopoly market in which one public firm(firm 0) and two private firms(firms 1 and 2) compete in a Cournot fashion. Each firm produces homogeneous products, $q_i\,(i=0,1,2)$, facing a linear inverse demand function, $P(Q)=a-Q$ where P is the market price and $Q=\sum_{i=0}^{2} q_i$ is the total industry output. The cost function of each firm is $C_i(q_i)$ and thus, the profit function of each firm is defined as

$$\pi_i = P(Q)\,q_i - C_i(q_i) \tag{1}$$

We assume that firm 0 is a public firm that is owned by the government while two firms 1 and 2 are domestic private firms.[10] We further assume that firm 2 owns a proportion of the shares of firm 1 under PPO, that is, the firm 2 does not affect the production decisions of firm 1. Social welfare is defined as the sum of the consumer surplus and domestic firms' profits, that is,

$$W = \frac{Q^2}{2} + \pi_0 + \pi_1 + \pi_2 \tag{2}$$

[10]In Section 4, we will also analyze the case of foreign firm and compare the results with domestic firm.

Each firm has different objective functions. We assume that firm 0 maximizes the welfare in (2) while firm 1 operates under PPO and thus maximizes its profits where the objective of firm 1 is:

$$V_1 = (1-\beta)\,\pi_1 \tag{3}$$

where $\beta \in [0,\ 0.5)$ is the degree of PPO by the firm 2, which implies that the upper limit of passive ownership is below 50%. Then, maximizing V_1 is the same as maximizing π_1. Firm 2 maximizes its total profit that is the sum of its own profit and the ownership earnings from the profit of the firm 1:

$$V_2 = \pi_2 + \beta\pi_1 \tag{4}$$

Finally, we consider the possibility of technology sharing between an efficient firm and an inefficient firm. For analytic simplicity, we assume that $C_i(q_i) = k_i q_i^2$, $i = 0,1,2$ where $k_i \in [0,1]$ represents the cost efficiency parameter of the firm.[11] Without technology sharing, we assume that firm 0 and firm 1 have the same standard level of technology, $k_0 = k_1 = 1$, while firm 2 is an efficient firm and has $k_2 = k \in [0,\ 1]$. For instance, if firm 2 shares its technology with firm 1, the cost condition under technology sharing[12] becomes $k_1 = k_2 = k$. This implies that if firm 2 transfers its advanced technology to firm 1, then firm 1 can produce its output with the same efficiency of firm 2.

We examine the two contrasting cases between nationalization (in a mixed market) and privatization (in a private market), respectively, and then compare the equilibrium outcomes. The game in each case runs as follows: In the first stage, firm 2 chooses whether to freely share its technology with firm 1, and then, each firm simultaneously and non-cooperatively chooses its output in a Cournot fashion in the last stage.

3. ANALYSIS WITH A DOMESTIC FIRM

3.1. ANALYSIS IN A MIXED MARKET

We examine a mixed market where the welfare-maximizing public firm competes with the other two private firms. In the last stage, each firm simultaneously

[11] We assume quadratic cost functions, which assure interior solutions in the equilibrium of mixed oligopolies in which public and private firms compete. For economic justifications, see, for example, Xu *et al.*(2016), Lee *et al.*(2018) and Kim *et al.*(2019), Xu and Lee(2021).

[12] If firm 1 has a superior technology while firm 0 and firm 2 have a standard technology, we can show that firm 1 never share its superior technology with firm 0 or firm 2.

chooses its output to maximize its objective equation (2), (3) and (4). Using the first order conditions, we obtain the followings.

$$\begin{aligned}
q_0^M &= \frac{a(1+2k_1)(1+2k_2)}{(1+2k_1)(1+2k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2))} \\
q_1^M &= \frac{2ak_0(1+2k_2)}{(1+2k_1)(1+2k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2))} \\
q_2^M &= \frac{2ak_0(1-\beta+2k_1)}{(1+2k_1)(1+2k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))} \\
Q^M &= \frac{a(2k_0(2-\beta+2k_1+2k_2)+(1+2k_1)(1+2k_2))}{(1+2k_1)(1+2k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))}
\end{aligned} \tag{5}$$

Note that an increase in PPO increases a collusive incentive of firm 2, which decreases its output. Since outputs are strategic substitutes, both outputs of the public firm and private firm 1 increase in the degree of PPO, but the total industry output decreases. That is, $\frac{\partial q_0^M}{\partial \beta} > 0$, $\frac{\partial q_1^M}{\partial \beta} > 0$, $\frac{\partial q_2^M}{\partial \beta} < 0$, and $\frac{\partial Q^M}{\partial \beta} < 0$.

Substituting the equilibrium outcomes yields the following profits, consumer surplus and welfare[13].

$$\begin{aligned}
\pi_0^M &= \frac{a^2k_0(1+2k_1)^2(1+2k_2)^2}{((1+2k_1)(1+2k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2)))^2} \\
\pi_1^M &= \frac{4a^2k_0^2(1+k_1)(1+2k_2)^2}{((1+2k_1)(1+2k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2)))^2} \\
\pi_2^M &= \frac{4a^2k_0^2(1-\beta+2k_1)(1+(1+\beta)k_2+2k_1(1+k_2))}{((1+2k_1)(1+2k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2)))^2} \\
\mathrm{CS}^M &= \frac{a^2((1+2k_1)(1+2k_2)+k_0(4-2\beta+4k_1+4k_2))^2}{2((1+2k_1)(1+2k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2)))^2} \\
W^M &= \frac{m_1}{2((1+2k_1)(1+2k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2)))^2}
\end{aligned} \tag{6}$$

In the case without technology sharing where the advanced technology is not transferred to the rival firm, firm 2 is the only efficient firm while domestic firm 0 and the firm 1 is inefficient, that is, $k_0 = k_1 = 1 > k_2 = k$. We provide the equilibrium outcomes of the last stage in Table 1 where the superscript MN indicates no technology sharing in a mixed market.

In the case with technology sharing where the advanced technology is transferred to domestic private firm 1, we have $\mathrm{k}_0 = 1 > k_1 = k_2 = k$. Using the similar analysis, we can obtain the equilibrium outcomes of the last stage in Table 2 where the superscript MT indicates a technology sharing in a mixed market.

[13]Note that m_i is defined in Appendix A.

$$q_0^{\mathrm{MN}} = \frac{3(a+2ak)}{17+22k-2\beta}, q_1^{\mathrm{MN}} = \frac{2(a+2ak)}{17+22k-2\beta}, q_2^{\mathrm{MN}} = \frac{2a(3-\beta)}{17+22k-2\beta},$$

$$Q^{\mathrm{MN}} = \frac{a(11+10k-2\beta)}{17+22k-2\beta}, \pi_0^{\mathrm{MN}} = \frac{9(a+2ak)^2}{(17+22k-2\beta)^2}, \pi_1^{\mathrm{MN}} = \frac{8(a+2ak)^2}{(17+22k-2\beta)^2},$$

$$\pi_2^{\mathrm{MN}} = \frac{4a^2(3-\beta)(3+k(3+\beta))}{(17+22k-2\beta)^2}, V_1^{\mathrm{MN}} = \frac{8(a+2ak)^2(1-\beta)}{(17+22k-2\beta)^2},$$

$$V_2^{\mathrm{MN}} = \frac{4a^2(9-\beta+k(9+(8+8k-\beta)\beta))}{(17+22k-2\beta)^2}, \mathrm{CS}^{\mathrm{MN}} = \frac{a^2(11+10k-2\beta)^2}{2(17+22k-2\beta)^2},$$

$$W^{\mathrm{MN}} = \frac{a^2(227+236k^2-4(17-\beta)\beta+k(428-8\beta(5+\beta)))}{2(17+22k-2\beta)^2}.$$

Table 1: Equilibrium results without technology sharing in a mixed market

$$q_0^{\mathrm{MT}} = \frac{a(1+2k)^2}{7+4k(5+3k)-2\beta}, q_1^{\mathrm{MT}} = \frac{2(a+2ak)}{7+4k(5+3k)-2\beta}, q_2^{\mathrm{MT}} = \frac{2a(1+2k-\beta)}{7+4k(5+3k)-2\beta},$$

$$\mathrm{Q}^{\mathrm{MT}} = \frac{a(5+4k(3+k)-2\beta)}{7+4k(5+3k)-2\beta}, \pi_0^{\mathrm{MT}} = \frac{a^2(1+2k)^4}{(7+4k(5+3k)-2\beta)^2}, \pi_1^{\mathrm{MT}} = \frac{4(1+k)(a+2ak)^2}{(7+4k(5+3k)-2\beta)^2},$$

$$\pi_2^{\mathrm{MT}} = \frac{4a^2(1+2k-\beta)(1+k(3+2k+\beta))}{(7+4k(5+3k)-2\beta)^2}, V_1^{\mathrm{MT}} = \frac{4(1+k)(a+2ak)^2(1-\beta)}{(7+4k(5+3k)-2\beta)^2},$$

$$V_2^{\mathrm{MT}} = \frac{4a^2(1+k(5+(3-\beta)\beta+8k(1+\beta)+4k^2(1+\beta)))}{(7+4k(5+3k)-2\beta)^2}, \mathrm{CS}^{\mathrm{MT}} = \frac{a^2(5+4k(3+k)-2\beta)^2}{2(7+4k(5+3k)-2\beta)^2},$$

$$W^{\mathrm{MT}} = \frac{a^2((1+2k)^2(43+4k(11+3k))-4(1+2k)(7+2k)\beta+4(1-2k)\beta^2)}{2(7+4k(5+3k)-2\beta)^2}.$$

Table 2: Equilibrium results with technology sharing in a mixed market

We compare the equilibrium outcomes between the two cases in a mixed market.

Lemma 1.

(i) $q_0^{\mathrm{MN}} > q_0^{\mathrm{MT}}$, $q_1^{\mathrm{MN}} < q_1^{\mathrm{MT}}$, $q_2^{\mathrm{MN}} > q_2^{\mathrm{MT}}$, $Q^{\mathrm{MN}} < Q^{\mathrm{MT}}$;

(ii) $\pi_0^{\mathrm{MN}} > \pi_0^{\mathrm{MT}}$, $\pi_1^{\mathrm{MN}} < \pi_1^{\mathrm{MT}}$, $\pi_2^{\mathrm{MN}} > \pi_2^{\mathrm{MT}}$, $\pi_1^{\mathrm{MN}} + \pi_2^{\mathrm{MN}} < \pi_1^{\mathrm{MT}} + \pi_2^{\mathrm{MT}}$;

(iii) $V_1^{\mathrm{MN}} < V_1^{\mathrm{MT}}$, $V_2^{\mathrm{MN}} \gtreqless V_2^{\mathrm{MT}}$ if $\beta \lesseqgtr \beta_M$ which satisfies $V_2^{\mathrm{MN}} = V_2^{MT}$;

(iv) $\mathrm{CS}^{\mathrm{MN}} < \mathrm{CS}^{\mathrm{MT}}$;

(v) $W^{\mathrm{MN}} < W^{MT}$.

Lemma 1 states that under technology sharing firm 1 increases its output while both firm 0 and firm 2 decrease the outputs, respectively, but the total outputs and consumer surplus increase. It also states that under technology sharing the profit of firm 1 increases since it can increase its output even though market price decreases wherein the output effect dominates the price effect. The operating profit of firm 2 decreases, but it can take some portion of the firm 1's profit and thus its objectives depend on the degree of PPO. Nevertheless, due to the collusive effect, the sum of profits between two firms under technology sharing is larger than that without technology sharing. However, social welfare always increases under technology sharing.

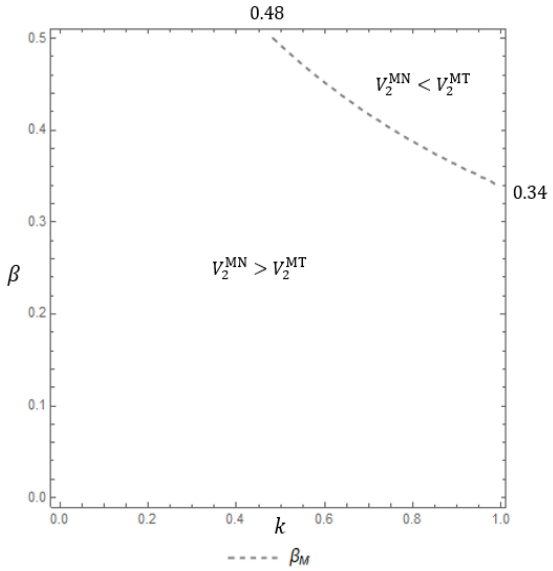
Proposition 1. *An efficient firm in a mixed market chooses technology sharing with its rival private firm when it has relatively high degree of PPO in the rival firm, which always increases welfare.*

Proposition 1 is represented by Figure 1. If the efficient firm has high degree of PPO, it can recover its profit loss caused by voluntary technology sharing from ownership share in the rival's profit. The reason is as follows: If the rival firm increases the output, then the public firm decreases output, which increases the profit of the rival firm. Hence, the efficient firm might have an incentive of technology sharing when it has high degree of PPO in the rival firm in the presence of an inefficient public firm. It implies that PPO and technology sharing have complementary relations. That is, the higher the technology gap, the higher degree of PPO is necessary for technology sharing to recover its profit loss from the rival firm's profit. This finding is contrast to the finding in Ghosh and Morita(2017) and Papadopoulos *et al*.(2019) in a private duopoly market, who showed that PPO and technology sharing are substitutes. We further show that technology sharing in a mixed market increase welfare even though the efficient firm has relatively high degree of PPO in the rival firm. This provides policy implications of PPO in competition policy.

3.2. ANALYSIS IN A PRIVATE MARKET

We also examine the other case that the public firm is fully privatized to the publics and thus, each firm maximizes its profits non-cooperatively. When firm 0 is a fully privatized firm, three private firms compete in a private market. Then, using the same procedure, we obtain the following equilibrium outputs.

Figure 1: The choice of technology sharing in a mixed market



$$
\begin{aligned}
q_0^P &= \frac{a(1+2k_1)(1+2k_2)}{4-\beta+6k_2+2k_1(3+4k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))} \\
q_1^P &= \frac{a(1+2k_0)(1+2k_2)}{4-\beta+6k_2+2k_1(3+4k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))} \\
q_2^P &= \frac{a(1+2k_0)(1-\beta+2k_1)}{4-\beta+6k_2+2k_1(3+4k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))} \\
Q^P &= \frac{a(3-\beta-2k_0(2-\beta+2k_1+2k_2)+4k_2+4k_1(1+k_2))}{4-\beta+6k_2+2k_1(3+4k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2))}
\end{aligned}
\tag{7}
$$

Note that an increase in PPO decreases the output of the efficient firm and total industry outputs, while increases the outputs of the firm 0 and firm 1. That is, $0 < \frac{\partial q_0^M}{\partial \beta} < \frac{\partial q_0^P}{\partial \beta}$, $0 < \frac{\partial q_1^M}{\partial \beta} < \frac{\partial q_1^P}{\partial \beta}$, $0 > \frac{\partial q_2^M}{\partial \beta} > \frac{\partial q_2^P}{\partial \beta}$ and $0 > \frac{\partial Q^M}{\partial \beta} > \frac{\partial Q^P}{\partial \beta}$. This finding in a private market is the same as in Lemma 1 in a mixed market. However, the rate of output changes in a private market is less(more) sensitive to the rival firms(the efficient firm) than those in a mixed market. Thus, regarding the effect of PPO on the changes of total outputs, the public firm in a mixed market responds less sensitively to the degree of PPO. This implies that the role of public firm is important to evaluate the anti-competitive effect of PPO.

Substituting the equilibrium outcomes yields the following profits, consumer surplus and welfare.

$$\begin{aligned}
\pi_0 &= \frac{a^2(1+k_0)(1+2k_1)^2(1+2k_2)^2}{(4-\beta+6k_2+2k_1(3+4k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \\
\pi_1 &= \frac{a^2(1+2k_0)^2(1+k_1)(1+2k_2)^2}{(4-\beta+6k_2+2k_1(3+4k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \\
\pi_2 &= \frac{(a+2ak_0)^2(1-\beta+2k_1)(1+(1+\beta)k_2+2k_1(1+k_2))}{(4-\beta+6k_2+2k_1(3+4k_2)+2k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \\
CS &= \frac{a^2(3-\beta+4k_2+4k_1(1+k_2)+k_0(4-2\beta+4k_1+4k_2))^2}{2(4-\beta+6k_2+k_1(6+8k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2)))^2} \\
W &= \frac{m_2}{2(4-\beta+6k_2+k_1(6+8k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2)))^2}
\end{aligned} \tag{8}$$

In the case without technology sharing where $k_0 = k_1 = 1 > k_2 = k$. We provide the equilibrium outcomes of the last stage in Table 3 where the superscript PN indicates no technology sharing in a private market.

$q_0^{\mathrm{PN}} = \frac{a(1+2k)}{8+10k-\beta}$, $q_1^{\mathrm{PN}} = \frac{a(1+2k)}{8+10k-\beta}$, $q_2^{\mathrm{PN}} = \frac{a(3-\beta)}{8+10k-\beta}$, $Q^{\mathrm{PN}} = \frac{a(5+4k-\beta)}{8+10k-\beta}$,
$\pi_0^{\mathrm{PN}} = \frac{2a(1+2k)^2}{(8+10k-\beta)^2}$, $\pi_1^{\mathrm{PN}} = \frac{2a(1+2k)^2}{(8+10k-\beta)^2}$, $\pi_2^{\mathrm{PN}} = \frac{a^2(3-\beta)(3+k(3+\beta))}{(8+10k-\beta)^2}$,
$V_1^{\mathrm{PN}} = \frac{2a(1+2k)^2(1-\beta)}{(8+10k-\beta)^2}$, $V_2^{\mathrm{PN}} = \frac{a^2(9-\beta+k(9+(8+8k-\beta)\beta))}{(8+10k-\beta)^2}$, $\mathrm{CS}^{\mathrm{PN}} = \frac{a^2(5+4k-\beta)^2}{2(8+10k-\beta)^2}$,
$W^{\mathrm{PN}} = \frac{a^2(51+48k^2-(16-\beta)\beta+2k(5-\beta)(9+\beta))}{2(8+10k-\beta)^2}$.

Table 3: Equilibrium results without technology sharing in a private market

In the case with voluntary technology sharing where $\mathrm{k}_0 = 1 > k_1 = k_2 = k$. We provide the equilibrium outcomes of the last stage in Table 4 where the superscript PT indicates voluntary technology sharing in a private market.

$q_0^{\mathrm{PT}} = \frac{a(1+2k)^2}{10+4k(7+4k)-3\beta}$, $q_1^{\mathrm{PT}} = \frac{3(a+2ak)}{10+4k(7+4k)-3\beta}$, $q_2^{\mathrm{PT}} = \frac{3a(1+2k-\beta)}{10+4k(7+4k)-3\beta}$,
$Q^{\mathrm{PT}} = \frac{a(7+4k(4+k)-3\beta)}{10+4k(7+4k)-3\beta}$, $\pi_0^{\mathrm{PT}} = \frac{2a^2(1+2k)^4}{(10+4k(7+4k)-3\beta)^2}$, $\pi_1^{\mathrm{PT}} = \frac{9(1+k)(a+2ak)^2}{(10+4k(7+4k)-3\beta)^2}$,
$\pi_2^{\mathrm{PT}} = \frac{9a^2(1+2k-\beta)(1+k(3+2k+\beta))}{(10+4k(7+4k)-3\beta)^2}$, $V_1^{\mathrm{PT}} = \frac{9(1+k)(a+2ak)^2(1-\beta)}{(10+4k(7+4k)-3\beta)^2}$,
$V_2^{\mathrm{PT}} = \frac{9a^2(1+k(5+(3-\beta)\beta+8k(1+\beta)+4k^2(1+\beta)))}{(10+4k(7+4k)-3\beta)^2}$, $\mathrm{CS}^{\mathrm{PT}} = \frac{a^2(7+4k(4+k)-3\beta)^2}{2(10+4k(7+4k)-3\beta)^2}$,
$W^{\mathrm{PT}} = \frac{a^2((1+2k)^2(89+20k(4+k))-12(5+k)(1+2k)\beta+9(1-2k)\beta^2)}{2(10+4k(7+4k)-3\beta)^2}$.

Table 4: Equilibrium results with technology sharing in a private market

We compare the equilibrium outcomes between the two in a private market.

Lemma 2.

(i) $q_0^{\mathrm{PN}} > q_0^{PT}$, $q_1^{\mathrm{PN}} < q_1^{PT}$, $q_2^{\mathrm{PN}} > q_2^{PT}$, $Q^{\mathrm{PN}} < Q^{PT}$;

(ii) $\pi_0^{\mathrm{PN}} > \pi_0^{PT}$, $\pi_1^{\mathrm{PN}} < \pi_1^{PT}$, $\pi_2^{\mathrm{PN}} > \pi_2^{PT}$, $\pi_1^{\mathrm{PN}} + \pi_2^{\mathrm{PN}} < \pi_1^{\mathrm{PT}} + \pi_2^{\mathrm{PT}}$;

(iii) $V_1^{\mathrm{PN}} < V_1^{PT}$, $V_2^{PT} \gtreqless V_2^{\mathrm{PN}}$ if $\beta \gtreqless \beta_P$ which satisfies $V_2^{\mathrm{PN}} = V_2^{PT}$;

(iv) $\mathrm{CS}^{\mathrm{PN}} < \mathrm{CS}^{PT}$;

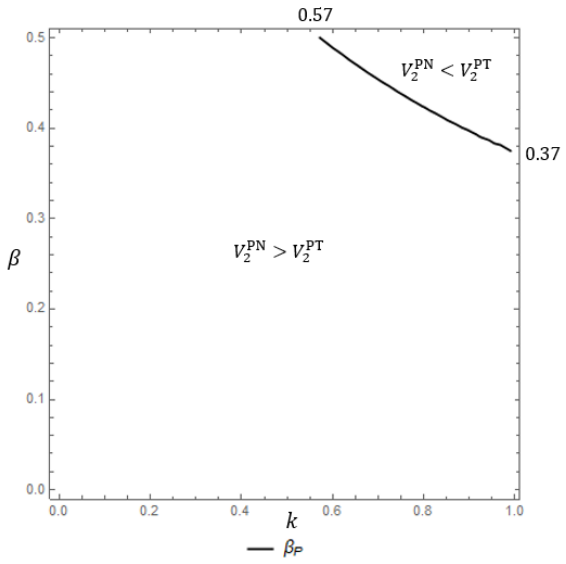
(v) $W^{\mathrm{PN}} < W^{PT}$.

Lemma 2 states that under technology sharing firm 1 increases its output while both firm 0 and firm 2 decrease the outputs, but total outputs and consumer surplus increase. It also states that under technology sharing the profit of firm 1 increases while the profits of firm 0 and firm 2 decrease. However, the sum of profits between firm 1 and firm 2 under technology sharing is larger than that without technology sharing. Again, firm 1 increases its objective value, while the objective value of firm 2 depends on the degree of PPO. Note that that the incentive of technology sharing in a private market weakens irrespective of the cost gap between firm 1 and firm 2. That is, $\beta_P > \beta_M$ for a given k. Finally, social welfare always increases under technology sharing. These findings also similar with Lemma 1 in a mixed market.

Proposition 2. *An efficient firm in a private market chooses technology sharing with its rival private firm when it has sufficiently high degree of PPO in the rival firm, which always increases welfare.*

Proposition 2 is represented by Figure 2. If the efficient firm has high degree of PPO, it can recover its profit loss caused by technology sharing from ownership share in the rival firm's profit. The reason is the same with Proposition 1 since PPO and technology sharing have complementary relations. However, the required degree of PPO in a private market is sufficiently higher than that in a mixed market. This is because the privatized firm 0 relatively less decreases its output under technology sharing and thus the effect of PPO on the changes of total outputs in a private market is less sensitive. That is, in the presence of public firm in a mixed market, it responds more sensitively to the technology sharing in which both domestic firms are more efficient than the public firm. Thus, given the same degree of PPO, the public firm decreases more outputs, compared to the privatization regime. Proposition 2 also shows that technology sharing in a private market increase welfare even though the efficient firm has relatively high degree of PPO in the rival firm. This also provides policy implications of PPO in competition and privatization policies.

Figure 2: The choice of technology sharing in a private market



3.3. THE EFFECT OF PRIVATIZATION POLICY

We compare the impact of privatization policy on the efficient firm's decision of technology sharing under PPO. For this, we compare the equilibrium results between private and mixed markets.

Lemma 3.

(i) $q_0^{\mathrm{MN}} > q_0^{\mathrm{PN}}$, $q_1^{\mathrm{MN}} < q_1^{\mathrm{PN}}$, $q_2^{\mathrm{MN}} < q_2^{\mathrm{PN}}$, and $Q^{\mathrm{MN}} > Q^{\mathrm{PN}}$;

(ii) $q_0^{\mathrm{MT}} > q_0^{\mathrm{PT}}$, $q_1^{\mathrm{MT}} < q_1^{\mathrm{PT}}$, $q_2^{\mathrm{MT}} < q_2^{\mathrm{PT}}$, and $Q^{\mathrm{MT}} > Q^{\mathrm{PT}}$;

(iii) $V_2^{\mathrm{MN}} < V_2^{\mathrm{PN}}$ and $V_2^{MT} < V_2^{PT}$.

Lemma 3 states that in a privatization regime, regardless of technology sharing, both firm 1 and firm 2 can increase their outputs and their objective values. However, privatization policy decreases total industry outputs irrespective of technology sharing. This is because privatization policy gets rid of the welfare-concerned incentive of the public firm that concerns not only industry profits but consumers surplus and thus the privatized firm will less aggressively produce the output irrespective of PPO.

Lemma 4.

(i) $W^{\mathrm{MN}} \lesseqgtr W^{\mathrm{PN}}$ if $k \lesseqgtr k_N = 0.62$;

(ii) $W^{MT} \lesseqgtr W^{PT}$ if $k \lesseqgtr k_T = 0.83$;

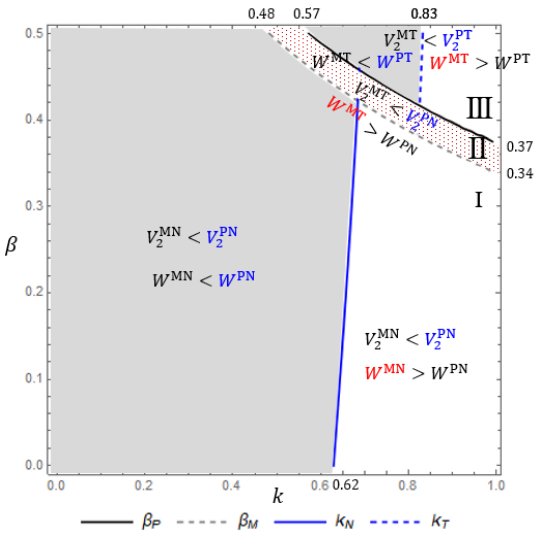
(iii) $W^{MT} > W^{\mathrm{PN}}$.

Lemma 4 states that in a privatization regime, regardless of technology sharing, social welfare decreases(increases) if the cost gap is relatively low(high). It is noteworthy that $0 < k_N < k_T < 1$. Thus, if cost gap in intermediate, i.e., $k_N < k < k_T$, privatization policy decreases(increases) welfare without(with) technology sharing, i.e., $W^{\mathrm{MN}} > W^{\mathrm{PN}}$ and $W^{MT} < W^{PT}$. Further, Lemma 4 (iii) states that welfare with technology sharing in a mixed market is always higher than that without technology sharing in a private market.

Proposition 3. *If the cost gap is not large and the efficient firm has higher degree of PPO in the rival firm, privatization policy might deter technology sharing and decrease the welfare.*

Proposition 3 is represented by Figure 3, which compares the incentive of technology sharing by an efficient firm in mixed and private markets, respectively. It provides different welfare implications. In region I, where $\beta < \beta_M$, technology sharing does not occur irrespective of privatization. In that case, however, privatization can increase welfare if the cost gap is relatively high. In region III, where $\beta > \beta_P$ technology sharing always occurs irrespective of privatization. In that case, however, privatization can increase welfare unless the cost gap is relatively low. Finally, in region II, technology sharing occurs only in a mixed market. That is, privatization can deter technology sharing and decrease welfare, as shown in Lemma 4 (ii).

Figure 3: Welfare effect of privatization policy



4. ANALYSIS WITH A FOREIGN FIRM

In this Section, we consider a case that an efficient licensor(firm 2) is a foreign firm and examine the welfare consequences of privatization policy. In this case, the social welfare is defined as

$$W = \frac{Q^2}{2} + \pi_0 + (1-\beta)\pi_1 \tag{9}$$

The objective of the public firm in a mixed market is changed with (9), while its objectives under privatization in a private market is the same since it maximizes its profit. Only difference in a private market is the social welfare consequences.

Using the similar analysis, we obtain the following equilibrium outputs in the last stage.

$$\begin{aligned}
q_0^{\mathrm{FM}} &= \frac{a(1+(1+\beta)k_2+2k_1(1+k_2))}{1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2))} \\
q_1^{\mathrm{FM}} &= \frac{ak_0(1+2k_2)}{1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2))} \\
q_2^{\mathrm{FM}} &= \frac{ak_0(1-\beta+2k_1)}{1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2))} \\
Q^{\mathrm{FM}} &= \frac{a(1+k_0(2-\beta+2k_1+2k_2)+(1+\beta)k_2+2k_1(1+k_2))}{1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2))}
\end{aligned} \tag{10}$$

Note that an increase in PPO decreases the output of the foreign firm and total industry outputs, while increases the outputs of the firm 0 and firm 1 increase. That is $\frac{\partial q_0^{\mathrm{FM}}}{\partial \beta} > \frac{\partial q_0^{\mathrm{FP}}}{\partial \beta} > 0$, $0 < \frac{\partial q_1^{\mathrm{FM}}}{\partial \beta} < \frac{\partial q_1^{\mathrm{FP}}}{\partial \beta}$, $0 > \frac{\partial q_2^{\mathrm{FM}}}{\partial \beta} > \frac{\partial q_2^{\mathrm{FP}}}{\partial \beta}$ and $0 > \frac{\partial Q^{\mathrm{FM}}}{\partial \beta} > \frac{\partial Q^{\mathrm{FP}}}{\partial \beta}$. This finding in a private market is the same as in Lemma 1. However, the rate of output changes in a private market is more sensitive to a licensee than those in a mixed market. This is because the PPO holding firm is a foreign firm, a public firm is more sensitive to change in PPO. Thus, regarding the effect of PPO on the changes of total outputs, the public firm in a mixed market responds more sensitively to the degree of PPO. This implies that the role of public firm is important to evaluate the anti-competitive effect of PPO.

Substituting the equilibrium outcomes yields the following results.

$$
\begin{aligned}
\pi_0^{\mathrm{FM}} &= \frac{a^2 k_0(1-\beta+2k_1)k_2(1+(1+\beta)k_2+2k_1(1+k_2))}{(1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \\
\pi_1^{\mathrm{FM}} &= \frac{a^2 k_0^2(1+k_1)(1+2k_2)^2}{(1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \\
\pi_2^{\mathrm{FM}} &= \frac{a^2 k_0^2(1-\beta+2k_1)(1+(1+\beta)k_2+2k_1(1+k_2))}{(1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \\
V_1^{\mathrm{FM}} &= \frac{a^2(1-\beta)k_0^2(1+k_1)(1+2k_2)^2}{(1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \\
V_2^{\mathrm{FM}} &= \frac{a^2 k_0^2(1+k_2+(k_1+\beta k_2)(4-\beta+4k_2+4k_1(1+k_2)))}{(1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \\
\mathrm{CS}^{\mathrm{FM}} &= \frac{a^2(1+(1+\beta)k_2+2k_1(1+k_2)+k_0(2-\beta+2k_1+2k_2))^2}{2(1+(1+\beta)k_2+2k_1(1+k_2)+k_0(3-\beta+4k_2+4k_1(1+k_2)))^2} \\
W^{\mathrm{FM}} &= \frac{m_3}{2((1+2k_1)(1+2k_2)+k_0(6-2\beta+8k_2+8k_1(1+k_2)))^2}
\end{aligned}
\tag{11}
$$

We can provide the equilibrium outcomes without technology sharing in Table 5 and technology sharing in Table 6. Note that the superscript FMN and FMT indicate no technology sharing and voluntary technology sharing by a foreign licensor in a mixed market, respectively.

$q_0^{\mathrm{FMN}} = \frac{a(3+k(3+\beta))}{10-\beta+k(11+\beta)}$, $q_1^{\mathrm{FMN}} = \frac{a(1+2k)}{10-\beta+k(11+\beta)}$, $q_2^{\mathrm{FMN}} = \frac{a(3-\beta)}{10-\beta+k(11+\beta)}$,
$Q^{\mathrm{FMN}} = \frac{a(7+5k-\beta+k\beta)}{10+11k-\beta+k\beta}$, $\pi_0^{\mathrm{FMN}} = \frac{a^2k(3-\beta)(3+k(3+\beta))}{(10-\beta+k(11+\beta))^2}$, $\pi_1^{\mathrm{FMN}} = \frac{2a(1+2k)^2}{(10-\beta+k(11+\beta))^2}$,
$\pi_2^{\mathrm{FMN}} = \frac{a^2(3-\beta)(3+k(3+\beta))}{(10-\beta+k(11+\beta))^2}$, $V_1^{\mathrm{FMN}} = \frac{2a(1+2k)^2(1-\beta)}{(10-\beta+k(11+\beta))^2}$,
$V_2^{\mathrm{FMN}} = \frac{a^2(9-\beta+k(9+(8+8k-\beta)\beta))}{(10-\beta+k(11+\beta))^2}$, $\mathrm{CS}^{\mathrm{FMN}} = \frac{a^2(7-\beta+k(5+\beta))^2}{2(10-\beta+k(11+\beta))^2}$,
$W^{\mathrm{FMN}} = \frac{a^2(53-(18-\beta)\beta+2k(4-\beta)(13+\beta)+k^2(59-\beta(6+\beta)))}{2(10-\beta+k(11+\beta))^2}$.

Table 5: Equilibrium results without technology sharing by a foreign firm in a mixed market

$$q_0^{\mathrm{FMT}} = \frac{a(1+k(3+2k+\beta))}{4-\beta+k(11+6k+\beta)},\ q_1^{\mathrm{FMT}} = \frac{a+2ak}{4-\beta+k(11+6k+\beta)},\ q_2^{\mathrm{FMT}} = \frac{a(1+2k-\beta)}{4-\beta+k(11+6k+\beta)},$$

$$Q^{\mathrm{FMT}} = \frac{a(3-\beta+k(7+2k+\beta))}{4-\beta+k(11+6k+\beta)},\ \pi_0^{\mathrm{FMT}} = \frac{a^2k(1+2k-\beta)(1+k(3+2k+\beta))}{(4-\beta+k(11+6k+\beta))^2},$$

$$\pi_1^{\mathrm{FMT}} = \frac{(1+k)(a+2ak)^2}{(4-\beta+k(11+6k+\beta))^2},\ \pi_2^{\mathrm{FMT}} = \frac{a^2(1+2k-\beta)(1+k(3+2k+\beta))}{(4-\beta+k(11+6k+\beta))^2},$$

$$V_1^{\mathrm{FMT}} = \frac{(1+k)(a+2ak)^2(1-\beta)}{(4-\beta+k(11+6k+\beta))^2},\ V_2^{\mathrm{FMT}} = \frac{a^2(1+k(5+(3-\beta)\beta+8k(1+\beta)+4k^2(1+\beta)))}{(4-\beta+k(11+6k+\beta))^2},$$

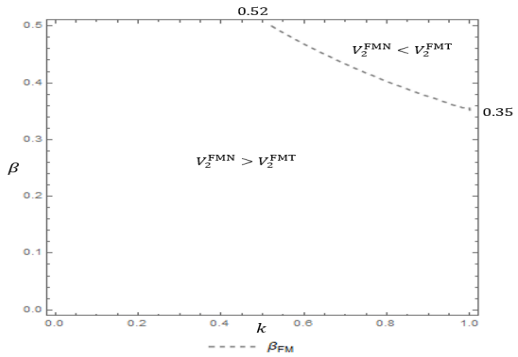
$$\mathrm{CS}^{\mathrm{FMT}} = \frac{a^2(3-\beta+k(7+2k+\beta))^2}{2(4-\beta+k(11+6k+\beta))^2},\ W^{\mathrm{FMT}} = \frac{\left\{\begin{array}{c} a^2((1+2k)^2(11+k(10+3k)) \\ -2(1+2k)(4+k(2+k))\beta+(1-k(2+k))\beta^2) \end{array}\right\}}{2(4-\beta+k(11+6k+\beta))^2}.$$

Table 6: Equilibrium results with technology sharing by a foreign firm in mixed market

Proposition 4. *An efficient foreign licensor in a mixed market chooses technology sharing when it has high degree of PPO in the rival firm, which always increase welfare.*

Proposition 4 is represented by Figure 4, which is similar with Fig.1 However, the incentive for technology sharing in a foreign licensor is reduced compared to the domestic firm in a mixed market(Note that the incentive of technology sharing of a foreign firm is weaker than that in a domestic firm. That is, $\beta_{\mathrm{FM}} > \beta_M$ for a given k).

Figure 4: The choices of technology of mixed market with a foreign firm



Next, we consider a private market. Then, the equilibrium results are the same as in Table 3 and 4, except social welfare, where

$$W^{\mathrm{FPN}} = \frac{a^2(11+8k(3+2k)-\beta)(3-\beta)}{2(8+10k-\beta)^2}$$

is the social welfare without technology sharing and

$$W^{\mathrm{FPT}} = \frac{a^2((1+2k)^2(71+62k+20k^2)-6(1+2k)(10+k(11+6k))\beta+9\beta^2)}{2(10+4k(7+4k)-3\beta)^2}$$

is the welfare under technology sharing by a foreign firm, respectively. Therefore, the incentive of technology sharing of a foreign firm is the same with that in a domestic firm.

Lemma 5.

(i) $\beta_P > \beta_{\mathrm{FM}}$;

(ii) $W^{\mathrm{FMN}} > W^{\mathrm{FPN}}$;

(iii) $W^{\mathrm{FM}T} \lesseqgtr W^{\mathrm{FP}T}$, if $k \lesseqgtr k_{\mathrm{FT}} = 0.3$;

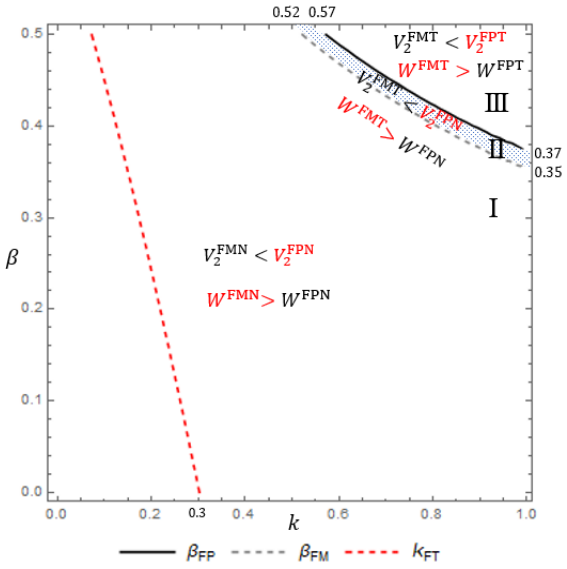
(iv) $W^{\mathrm{FM}T} > W^{\mathrm{FPN}}$.

Lemma 5 (i) states that the incentive of technology sharing in a private market is weaker than that in a mixed market. It also shows that regardless of technology sharing, welfare in a mixed market is always higher than that in a private market. Further, Lemma 5 (iii) states that welfare with technology sharing in a mixed market is always higher than that without technology sharing in a private market(Note that $k > k_{\mathrm{FT}}$, we have $W^{\mathrm{FM}T} > W^{\mathrm{FP}T}$).

Proposition 5. *If the cost gap is not large and a foreign licensor has higher degree of PPO in the rival firm, privatization might deter technology sharing and decrease the welfare.*

Proposition 5 is represented by Figure 5, which compares the incentive of technology sharing by a foreign licensor in mixed and private markets and shows welfare implications. Specifically, in region I, where $\beta < \beta_{\mathrm{FM}}$, technology sharing does not occur irrespective of privatization and thus privatization can decrease welfare. In region III, where $\beta > \beta_{\mathrm{FP}}$, technology sharing always occurs irrespective of privatization, but privatization also can decrease welfare. Finally, in region II, technology sharing occurs only in a mixed market. That is, privatization can deter technology sharing. Further, Lemma 5 (iii) shows that privatization can decrease welfare.

Figure 5: Welfare effect of privatization policy with a foreign firm



5. CONCLUDING REMARK

This study investigated the interaction between PPO and voluntary technology transfer by an efficient private firm in the presence of public firm, and examined the effects of privatization policy when the efficient firm is either a domestic firm or a foreign one. We showed that an efficient firm in both private and mixed markets chooses technology sharing with its rival private firm when it has sufficiently high degree of PPO in the rival firm, and this technology sharing always increases welfare. That is, irrespective of the presence of the public firm, technology sharing increase welfare with a high degree of PPO. This provides policy implications of PPO in competition policy. We also showed that privatization might deter technology sharing and decrease welfare if an efficient firm has relatively high degree of PPO and the cost gap is not large. However, if a shareholding company is an efficient foreign firm, privatization policy can increase deterrence effect and thus always decrease the welfare.

There still remain future works because of its model-specific assumptions where two extreme cases between full nationalization and complete privatiza-

tion are examined. One possible extension is to consider optimal level of partial privatization, which will intermediate the two extreme cases. The analysis with the other type of technology sharing such as fee (fixed fee or royalty) technology is also important. Finally, it is also promising to examine strategic level of PPO under product differentiation with different market structure as future research of this study.

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APPENDIX A: The value of m_i

$m_1 = a^2((1+2k_1)^2(1+2k_2)^2 + 2k_0(1+2k_1)(1+2k_2)(5-2\beta+6k_2+k_1(6+4k_2)) + 4k_0^2((4-\beta)(2-\beta)+4k_1^2(3+2k_2)+2k_2(9-\beta(2+\beta)+6k_2)+k_1(18-8\beta+8k_2(3+k_2))))$

$m_2 = a^2(15-8\beta+\beta^2+2(3-\beta)(7+\beta)k_2+32k_2^2+8k_1^2(4+9k_2+6k_2^2)+2k_1(21-6\beta+4k_2(13-\beta+9k_2)) +4k_0^2\left((4-\beta)(2-\beta)+4k_1^2(3+2k_2)+2k_2(9-\beta(2+\beta)+6k_2)+k_1(18\right.$
$2k_0(21-2(7-\beta)\beta+4k_1^2(3+2k_2)^2+4k_2(13-\beta(3+\beta)+9k_2)+k_1(52-20\beta+8k_2(12-\beta+6k_2))))$

$m_3 = a^2(2k_0(2-\beta+(3-\beta)k_2+2k_1(1+k_2))(1+(1+\beta)k_2+2k_1(1+k_2))+(1+(1+\beta)k_2+2k_1(1+k_2))^2+k_0^2(6-(6-\beta)\beta+4k_1^2+4k_2(4-3\beta+(3-2\beta)k_2)+2k_1(5-3\beta+4k_2(2+\beta+(1-\beta)k_2))))$

APPENDIX B: Proofs of Lemmas and Propositions

Proof of Lemma 1.

From the equilibrium result in Table 1 and Table 2, we can show that

$q_0^{\mathrm{MN}} - q_0^{\mathrm{MT}} = \frac{4a(1-k)(1+2k)(1+2k-\beta)}{(17+22k-2\beta)(7+20k+12k^2-2\beta)} > 0,$

$q_1^{\mathrm{MN}} - q_1^{\mathrm{MT}} = -\frac{4a(1-k)(1+2k)(5+6k)}{(17+22k-2\beta)(7+20k+12k^2-2\beta)} < 0,$

$q_2^{\mathrm{MN}} - q_2^{\mathrm{MT}} = \frac{4a(1-k)(1+2k)(2+3\beta)}{(17+22k-2\beta)(7+4k(5+3k)-2\beta)} > 0,$

$Q^{\mathrm{MN}} - Q^{\mathrm{MT}} = -\frac{8a(1-k)(1+2k)(1+2k-\beta)}{(17+22k-2\beta)(7+4k(5+3k)-2\beta)} < 0,$

$\pi_0^{\mathrm{MN}} - \pi_0^{\mathrm{MT}} = \frac{8a^2(1-k)(1+2k)^2(1+2k-\beta)(19+58k+40k^2-4\beta-2k\beta)}{(17+22k-2\beta)^2(7+20k+12k^2-2\beta)^2} > 0,$

$\pi_1^{\mathrm{MN}} - \pi_1^{\mathrm{MT}} = -\frac{4(1-k)(a+2ak)^2(191+764k^2+288k^3+k(668-8\beta)-4\beta(3+\beta))}{(17+22k-2\beta)^2(7+4k(5+3k)-2\beta)^2} < 0,$

$\pi_2^{\mathrm{MN}} - \pi_2^{\mathrm{MT}} = \frac{\left\{\begin{array}{c} 8a^2(1-k)(1+2k)(4(1+k)(1+2k)(19+20k) \\ -(21+4k(2-5k))\beta+2(2+3k)(6+k(19+6k))\beta^2-4(1+3k)\beta^3)\end{array}\right\}}{(17+22k-2\beta)^2(7+4k(5+3k)-2\beta)^2} > 0,$

$\left(\pi_1^{\mathrm{MN}}+\pi_2^{\mathrm{MN}}\right)-\left(\pi_1^{\mathrm{MT}}+\pi_2^{\mathrm{MT}}\right) = \frac{\left\{\begin{array}{c} 4a^2(1-k)(1+2k)(39+2k(217+2k(329+2k(187+72k))) \\ +30\beta-8k(2+7k)\beta-4(13+k(58+3k(23+6k)))\beta^2+8(1+3k)\beta^3\end{array}\right\}}{(17+22k-2\beta)^2(7+4k(5+3k)-2\beta)^2} <$
$0,$

$V_1^{\mathrm{MN}} - V_1^{\mathrm{MT}} = -\frac{4(1-k)(a+2ak)^2(1-\beta)(191+764k^2+288k^3+k(668-8\beta)-4\beta(3+\beta))}{(17+22k-2\beta)^2(7+4k(5+3k)-2\beta)^2} < 0,$

$V_2^{\mathrm{MN}} - V_2^{\mathrm{MT}} = \frac{\left\{\begin{array}{l} 4a^2(1-k)(1+2k)(8(1+k)(1+2k)(19+20k) \\ -(233+2k(533+2k(515+2k(227+72k))))\beta \\ +4(15+k(64+k(73+18k)))\beta^2-4(1+4k)\beta^3)\end{array}\right\}}{(17+22k-2\beta)^2(7+4k(5+3k)-2\beta)^2} \begin{array}{c}\geq \\ < \end{array} 0,$ if $\beta \begin{array}{c}\leq \\ > \end{array} \beta_M$ where $\beta_M \equiv \beta(k)$, which satisfies $V_2^{\mathrm{MN}} = V_2^{\mathrm{MT}}$,

$\mathrm{CS}^{\mathrm{MN}} - \mathrm{CS}^{\mathrm{MT}} = -\frac{\left\{\begin{array}{c} 8a^2(1-k)(1+2k)(1+2k-\beta) \\ (81+302k+332k^2+104k^3-8(5+2k(4+k))\beta+4\beta^2)\end{array}\right\}}{(17+22k-2\beta)^2(7+4k(5+3k)-2\beta)^2} < 0.$

$$W^{\mathrm{MT}} - W^{\mathrm{MN}} = \frac{\left\{\begin{array}{c} 4a^2(1-k)(1+2k)(163+2k(547+2k(623+2k(281+84k)))) \\ -166\beta-8k(85+3k(27+4k))\beta+4(7-9k(3+k)(1+2k))\beta^2+24k\beta^3) \end{array}\right\}}{(17+22k-2\beta)^2(7+4k(5+3k)-2\beta)^2} > 0.$$

Proof of Lemma 2.

From the equilibrium result in Table 3 and Table 4, we can show that

$$q_0^{\mathrm{PN}} - q_0^{\mathrm{PT}} = \frac{2a(1-k)(1+2k)(1+2k-\beta)}{(10+28k+16k^2-3\beta)(8+10k-\beta)} > 0,$$

$$q_1^{\mathrm{PN}} - q_1^{\mathrm{PT}} = -\frac{2a(1-k)(1+2k)(7+8k)}{(10+28k+16k^2-3\beta)(8+10k-\beta)} < 0,$$

$$q_2^{\mathrm{PN}} - q_2^{\mathrm{PT}} = \frac{2a(1-k)(1+2k)(3+4\beta)}{(10+4k(7+4k)-3\beta)(8+10k-\beta)} > 0,$$

$$Q^{\mathrm{PN}} - Q^{\mathrm{PT}} = -\frac{6a(1-k)(1+2k)(1+2k-\beta)}{(10+4k(7+4k)-3\beta)(8+10k-\beta)} < 0,$$

$$\pi_0^{\mathrm{PN}} - \pi_0^{\mathrm{PT}} = \frac{8a^2(1-k)(1+2k)^2(1+2k-\beta)(9+27k+18k^2-2\beta-k\beta)}{(10+28k+16k^2-3\beta)^2(8+10k-\beta)^2} > 0,$$

$$\pi_1^{\mathrm{PN}} - \pi_1^{\mathrm{PT}} = -\frac{a^2(1-k)(1+2k)^2(376+1272k+1404k^2+512k^3-24\beta-12k\beta-9\beta^2)}{(10+28k+16k^2-3\beta)^2(8+10k-\beta)^2} < 0,$$

$$(\pi_1^{\mathrm{PN}} + \pi_2^{\mathrm{PN}}) - (\pi_1^{\mathrm{PT}} + \pi_2^{\mathrm{PT}}) = -\frac{\left\{\begin{array}{c} a^2(1-k)(1+2k)(4(1+2k)(13+2k(78+k(135+64k))) \\ +12(8+(5-4k)k)\beta-(1+2k)(117+32k(7+2k))\beta^2+6(3+8k)\beta^3) \end{array}\right\}}{(10+4k(7+4k)-3\beta)^2(8+10k-\beta)^2} < 0$$

$$\pi_2^{\mathrm{PN}} - \pi_2^{\mathrm{PT}} = \frac{\left\{\begin{array}{c} 2a^2(1-k)(1+2k)(162(1+k)^2(1+2k)-12(5+(5-k)k)\beta \\ +2(1+2k)(27+8k(7+2k))\beta^2-3(3+8k)\beta^3) \end{array}\right\}}{(10+4k(7+4k)-3\beta)^2(-8-10k+\beta)^2} > 0,$$

$$V_1^{\mathrm{PN}} - V_1^{\mathrm{PT}} = -\frac{a^2(1-k)(1+2k)^2(1-\beta)(376+1272k+1404k^2+512k^3-24\beta-12k\beta-9\beta^2)}{(10+28k+16k^2-3\beta)^2(8+10k-\beta)^2} < 0.$$

$$V_2^{\mathrm{PN}} - V_2^{\mathrm{PT}} = \frac{\left\{\begin{array}{c} a^2(1-k)(1+2k)(324(1+k)^2(1+2k) \\ -4(124+k(536+k(981+830k+256k^2)))\beta \\ +4(3+k)(1+2k)(11+16k)\beta^2+3(3+10k)\beta^3) \end{array}\right\}}{(10+4k(7+4k)-3\beta)^2(8+10k-\beta)^2} \underset{<}{\overset{\geq}{0}}, \text{ if } \beta \underset{>}{\overset{\leq}{\beta}}_P \text{ where } \beta_{\mathrm{PNT}} \equiv \beta(k),$$

which satisfies $V_2^{\mathrm{PT}} = V_2^{\mathrm{PN}}$.

$$\mathrm{CS}^{\mathrm{PN}} - \mathrm{CS}^{\mathrm{PT}} = -\frac{\left\{\begin{array}{c} 6a^2(1-k)(1+2k)(1+2k-\beta) \\ (53+189k+192k^2+52k^3-28\beta-43k\beta-10k^2\beta+3\beta^2) \end{array}\right\}}{(10+28k+16k^2-3\beta)^2(8+10k-\beta)^2} < 0.$$

$$W^{\mathrm{PN}} - W^{\mathrm{PT}} = -\frac{\left\{\begin{array}{c} a^2(1-k)(1+2k)(2(1+2k)(149+k(699+4k(207+67k))) \\ -2(151+2k(309+4k(69+7k)))\beta+(53-4k(51+k(117+32k)))\beta^2+48k\beta^3) \end{array}\right\}}{(10+4k(7+4k)-3\beta)^2(8+10k-\beta)^2} < 0$$

Proof of Lemma 3.

From the equilibrium result in Table 1 and Table 3, we can show that

$$q_0^{\mathrm{MN}} - q_0^{\mathrm{PN}} = \frac{(a+2ak)(7+8k-\beta)}{(17+22k-2\beta)(8+10k-\beta)} > 0,$$

$$q_1^{\mathrm{MN}} - q_1^{\mathrm{PN}} = -\frac{a(1+2k)^2}{(17+22k-2\beta)(8+10k-\beta)} < 0,$$

$$q_2^{\mathrm{MN}} - q_2^{\mathrm{PN}} = -\frac{a(1+2k)^2}{(17+22k-2\beta)(8+10k-\beta)} < 0,$$

$$Q^{\mathrm{MN}} - Q^{\mathrm{PN}} = \frac{3a(1+2k)^2}{(17+22k-2\beta)(8+10k-\beta)} > 0,$$

$$q_0^{\mathrm{MT}} - q_0^{\mathrm{PT}} = \frac{a(1+2k)^2(3+8k+4k^2-\beta)}{(10+28k+16k^2-3\beta)(7+20k+12k^2-2\beta)} > 0,$$

$$q_1^{\mathrm{MT}} - q_1^{\mathrm{PT}} = -\frac{a(1+2k)^3}{(10+4k(7+4k)-3\beta)(7+4k(5+3k)-2\beta)} < 0,$$
$$q_2^{\mathrm{MT}} - q_2^{\mathrm{PT}} = -\frac{a(1+2k)^2(1+2k-\beta)}{(10+4k(7+4k)-3\beta)(7+4k(5+3k)-2\beta)} < 0,$$
$$Q^{\mathrm{MT}} - Q^{\mathrm{PT}} = \frac{a(1+2k)^4}{(10+4k(7+4k)-3\beta)(7+4k(5+3k)-2\beta)} > 0.$$
$$V_2^{\mathrm{MN}} - V_2^{\mathrm{PN}} = -\frac{a^2(1+2k)(33+42k-4\beta)(9-\beta+k(9+(8+8k-\beta)\beta))}{(17+22k-2\beta)^2(8+10k-\beta)^2} < 0,$$
$$V_2^{\mathrm{MT}} - V_2^{\mathrm{PT}} = -\frac{\left\{\begin{array}{c} a^2(1+2k)((1+k)(5-2k)(1+2k)(37+38k) \\ +(237+2k(377+2k(159-2k(87+8k(22+9k)))))\beta \\ -(1+2k)(60+k(31-4k(25+9k)))\beta^2+4(1+2k-4k^2)\beta^3) \end{array}\right\}}{(7+4k(5+3k)-2\beta)^2(8+10k-\beta)^2} < 0,$$
$$V_2^{\mathrm{MT}} - V_2^{\mathrm{PT}} = -\frac{\left\{\begin{array}{c} (a+2ak)^2(41+4k(29+17k)-12\beta) \\ \left(1+k\left(5+(3-\beta)\beta+8k(1+\beta)+4k^2(1+\beta)\right)\right) \end{array}\right\}}{(10+4k(7+4k)-3\beta)^2(7+4k(5+3k)-2\beta)^2} < 0.$$

Proof of Lemma 4.

From the equilibrium result in Table 1 and Table 3, we can show that

$$W^{\mathrm{MN}} - W^{\mathrm{PN}} = \frac{\left\{\begin{array}{c} a^2(1+2k)(-211+184k^3+2(54-5\beta)\beta \\ -2k(12+(2-\beta)\beta(39-4\beta))+12k^2(38-\beta(26-7\beta))) \end{array}\right\}}{2(17+22k-2\beta)^2(8+10k-\beta)^2} \underset{>}{\leq} 0, \text{ if } k \underset{>}{\leq} k_N \text{ where}$$

$k_N \equiv k(\beta)$, which satisfies $W^{\mathrm{MN}} = W^{\mathrm{PN}}$.

$$W^{\mathrm{MT}} - W^{\mathrm{PT}} = \frac{\left\{\begin{array}{c} (a+2ak)^2((1+2k)^3(-61+2k(3+2k(19+6k))) \\ +4(1+2k)^2(13-k(21+22k))\beta-2(1+2k)(5-k(55+34k))\beta^2-24k\beta^3) \end{array}\right\}}{2(10+4k(7+4k)-3\beta)^2(7+4k(5+3k)-2\beta)^2} \underset{>}{\leq} 0, \text{ if}$$

$k \underset{<}{\geq} k_T$ where $k_T \equiv k(\beta)$, which satisfies $W^{\mathrm{MT}} = W^{\mathrm{PT}}$.

$$W^{\mathrm{MT}} - W^{\mathrm{PN}} = \frac{\left\{\begin{array}{c} a^2(1+2k)(253+4k(377+k(591-2k(29+4k(76+33k)))) \\ -268\beta-4k(221+2k(7-2k(47+6k)))\beta \\ +2(23-k(105+2k(43-18k(5+2k))))\beta^2+8k(5-6k)\beta^3) \end{array}\right\}}{2(7+4k(5+3k)-2\beta)^2(8+10k-\beta)^2} > 0.$$

Proof of Lemma 5.

From the equilibrium result of a foreign licensor, we can show that

$$W^{\mathrm{FMN}} - W^{\mathrm{FPN}} = \frac{\left\{\begin{array}{c} a^2(2+k+k\beta)(46+k(315+4k(96+23k))+30\beta \\ +k(77+4k(59+47k))\beta-4(1-4k)(1+k+k^2)\beta^2-2k\beta^3) \end{array}\right\}}{2(8+10k-\beta)^2(10-\beta+k(11+\beta))^2} > 0,$$
$$W^{\mathrm{FMT}} - W^{\mathrm{FPN}} = \frac{\left\{\begin{array}{c} a^2((1+2k)^2(176+k(456+k(99-4k(80+33k)))) \\ -2(1+2k)(100+k(295+4k(17-k(89+4k(23+9k)))))\beta \\ +(42+k(84-k(67-4k(8+k(89+48k)))))\beta^2-2(1-k-9k^2+2k^3-8k^4)\beta^3-2k^2\beta^4) \end{array}\right\}}{2(8+10k-\beta)^2(4-\beta+k(11+6k+\beta))^2} >$$

0,

$$W^{\mathrm{FMT}} - W^{\mathrm{FPT}} = \frac{\left\{\begin{array}{c} a^2((1+2k)^3(-18+k(41+2k(29+6k))) \\ +(1+2k)^2(34+k(31+8k(9+5k)))\beta \\ -2(1+2k)(1-3k)(4+k(3+2k))\beta^2-6k\beta^3)(2+k(5+2k+3\beta)) \end{array}\right\}}{2(10+4k(7+4k)-3\beta)^2(4-\beta+k(11+6k+\beta))^2} \underset{>}{\leq} 0, \text{ if } k \underset{>}{\leq} k_{\mathrm{FT}}$$

where $k_{\mathrm{FT}} \equiv k(\beta)$, which satisfies $W^{\mathrm{FPT}} = W^{\mathrm{FMT}}$.

Proof of Proposition 4.

From the equilibrium result in Table 5 and Table 6, we can show that

$$W^{\mathrm{FMT}} - W^{\mathrm{FMN}} = \frac{\left\{ \begin{array}{c} a^2(1-k)(1+2k)((1-\beta)(126-(28-\beta)\beta)+12k^4(14-\beta(10+\beta)) \\ +k(620-2\beta(277+2(5-2\beta)\beta))+k^2(1061-\beta(681+5\beta(21+\beta))) \\ +2k^3(367-\beta(201+\beta(30+\beta)))) \end{array} \right\}}{(10-\beta+k(11+\beta))^2(4-\beta+k(11+6k+\beta))^2} > 0$$