Patent Protection and R&D Subsidy Under Asymmetric Information

Haejun JEON

Osaka University

5th Asian Quantitative Finance Conference
March 26th

Seoul, South Korea

Introduction

We examine a licensing contract in vertically separated market in the presence of asymmetric information.

- An innovator develops new technology that can save running costs of a manufacturer which cannot identify the quality.

Perfect patent protection is optimal under symmetric information whereas it is not under asymmetric information.

- Social welfare under asymmetric information is higher than that under symmetric information for most patent protection.

R&D subsidy is suboptimal under symmetric information whereas it can be optimal under asymmetric information.

- The subsidy neither stimulates nor stifles the innovation under asymmetric information.

Information asymmetry induces under/overinvestment of less/more efficient innovators, respectively.

- The effects become clearer in the presence of R&D subsidy.

Related literature

A signaling game in technology market

- License contract terms: Gallini and Wright (1990), Beggs (1992), Martimort et al. (2010)
- Information disclosure: Bhattacharya and Ritter (1983), Anton and Yao (1994, 2003, 2004), Gick (2008)
- They did not consider the innovator's investment decision. We endogenize it and regard its timing as a signal of the quality.

A signaling via investment timing

- Morellec and Schürhoff (2011): a firm's investment and financing decision
- Bustamante (2012): IPO market with a signaling
- Grenadier and Malenko (2011): a formulation of the framework and its applications on corporate finance

Vertical separation

A downstream firm makes a product whose demand shock follows

$$\mathrm{d}X_t = \mu X_t \mathrm{d}t + \sigma X_t \mathrm{d}W_t \tag{1}$$

The firm makes revenue flows πX_t with running costs c, and thus, its current value is

$$\mathbb{E}\Big[\int_t^{\infty} e^{-r(s-t)}(\pi - c)X_s \mathrm{d}s \Big| X_t = x\Big] = \frac{(\pi - c)x}{r - \mu} \tag{2}$$

An upstream firm can develop new technology that can save the downstream firm's running costs by $\gamma \in (0, 1)$.

- The R&D investment costs δ and the upstream firm can only raise revenue by licensing the technology.
- The upstream and downstream firms take a fraction λ and $1 - \lambda$ of the surplus from the innovation, respectively, where $\lambda \in [0, 1]$ stands for the degree of patent protection.

Asymmetric information

Two different types of innovators

- Type g dominates type b in terms of the quality of technology and the R&D cost efficiency (i.e., $\gamma_g > \gamma_b$ and $\delta_g < \delta_b$).
- Namely, type g can develop more innovative technology at even lower costs, but the downstream firm cannot observe the true type of the upstream firm.
- The probability that the upstream firm's type is g and b is given by p and $1 - p$, respectively, where $p \in (0, 1)$ denotes the proportion of more efficient innovators.

We only focus on the (least-cost) separating equilibrium in the present model.

- A pooling equilibrium does not satisfy the Intuitive Criterion and suffers from the multiplicity of equilibrium.

Benchmark model: symmetric information

If the downstream firm can identify the upstream firm's true type, the value of upstream firm of type $i \in \{g, b\}$ is

$$U_i^s(x) = \left[\frac{\lambda\gamma_i c X_i}{r-\mu} - \delta_i\right]\left(\frac{x}{X_i}\right)^{\alpha} \quad \text{where } X_i = \frac{\alpha(r-\mu)\delta_i}{(\alpha-1)\lambda\gamma_i c} \tag{3}$$

Note that $X_g < X_b$ and $\partial X_i / \partial \lambda < 0$ hold.

- The dominant firm invests earlier than the dominated one.
- Strong patent protection stimulates the innovation.

The downstream firm adopts the cost-saving technology instantly.

$$D_i^s(x) = \frac{(\pi - c)x}{r-\mu} + \frac{(1-\lambda)\gamma_i c X_i}{r-\mu}\left(\frac{x}{X_i}\right)^{\alpha} \tag{4}$$

Note that $\partial D_i^s(x)/\partial X_i < 0$ holds.

- The earlier the innovation is made, the higher the downstream firm's value becomes ($\because$ it is a free rider of the innovation).

Welfare analysis under symmetric information

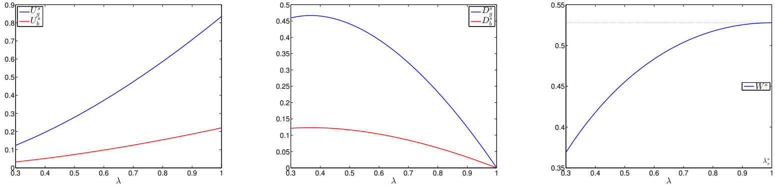
Social welfare is evaluated as

$$W^s(x) = pW_g^s(x) + (1-p)W_b^s(x) \tag{5}$$

where

$$W_i^s(x) = U_i^s(x) + D_i^s(x) = \frac{(\pi - c)x}{r-\mu} + \left[\frac{\gamma_i c X_i}{r-\mu} - \delta_i\right]\left(\frac{x}{X_i}\right)^{\alpha} \tag{6}$$

Note that social welfare coincides with the value of a hypothetical firm into which the firms are vertically integrated.



(a) Upstream firm (b) Downstream firm (c) Social welfare

Implications on the policies

The upstream firm's value strictly increases in λ, whereas that of the downstream firm does not strictly decrease in λ.

- The increase of λ gets the innovation advanced, which raises the downstream firm's value while λ is sufficiently low.
- After λ exceeds a certain level, the burden of higher royalties dominates the gains from earlier innovation, and the downstream firm's value starts to decrease in λ.

Perfect patent protection is optimal under symmetric information (i.e., $\lambda_s^* = 1$).

- The whole surplus from innovation should be apportioned to the one to which the innovation is attributed.
- That is, a free ride on innovation should not be allowed under symmetric information.
- It yields the optimal investment of the hypothetical firm with profits flow $\gamma_i c X_t$ and investment costs δ_i in (6).

Main model: asymmetric information

Suppose the downstream firm cannot identify the technology's quality before use and a license contract is irreversible.

- Given higher royalties for type g firm, type b has an incentive to mimic type g's investment behavior.
- Despite the incomplete information, the timing of R&D investment can be observed and it becomes a signal.

If type i firm invests at the threshold X and the quality of its technology is perceived as γ, the firm value is evaluated as

$$U_i^a(x; X, \gamma) = \left[\frac{\lambda\gamma c X}{r-\mu} - \delta_i\right]\left(\frac{x}{X}\right)^{\alpha} \quad \forall i \in \{g, b\} \tag{7}$$

The elasticity of substitution between γ and X is

$$\frac{\partial \gamma}{\partial X}\frac{X}{\gamma} = -\frac{\frac{\partial}{\partial X}U_i^a(x; X, \gamma)}{\frac{\partial}{\partial \gamma}U_i^a(x; X, \gamma)}\frac{X}{\gamma} = (\alpha - 1) - \frac{\alpha\delta_i(r-\mu)}{\lambda\gamma c X} \tag{8}$$

which shows that the single crossing condition holds (i.e., (8) negatively depends on δ_i and $\delta_g < \delta_b$).

Incentive compatability conditions

The condition (8) implies that type g finds it less costly to distort its investment timing than type b.

- Type g can choose to invest earlier so that the downstream firm can identify the true type.

Type b firm has an incentive to mimic type g by investing at the trigger X when the following condition holds:

$$\left[\frac{\lambda\gamma_g cX}{r-\mu}-\delta_b\right]\left(\frac{x}{X}\right)^{\alpha} \geq \left[\frac{\lambda\gamma_b cX_b}{r-\mu}-\delta_b\right]\left(\frac{x}{X_b}\right)^{\alpha} = U_b^s(x) \tag{9}$$

which yields X^* under which type b gives up on mimicking type g.

Similarly, type g firm's ICC to separate itself from type b is

$$\left[\frac{\lambda\gamma_g cX}{r-\mu}-\delta_g\right]\left(\frac{x}{X}\right)^{\alpha} \geq \left[\frac{\lambda\gamma_b cX_b}{r-\mu}-\delta_g\right]\left(\frac{x}{X_b}\right)^{\alpha} \tag{10}$$

We can derive $X^*_{\max}$ over which type g gives up on separating itself from type b (the separating equilibrium exists only if $X^* \leq X^*_{\max}$).

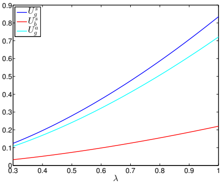
Welfare analysis under asymmetric information

Based on these arguments, we can summarize the firm values and social welfare under asymmetric information as follows:

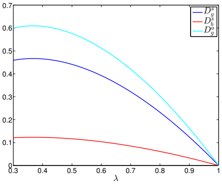
$$U_g^a(x) = \begin{cases} \left[\frac{\lambda\gamma_g cX^*}{r-\mu} - \delta_g\right]\left(\frac{x}{X^*}\right)^\alpha & \text{if } X^* < X_g \\ U_g^s(x) & \text{if } X^* \geq X_g \end{cases} \qquad U_b^a(x) = U_b^s(x)$$

$$D_g^a(x) = \begin{cases} \frac{(\pi-c)x}{r-\mu} + \left[\frac{(1-\lambda)\gamma_g cX^*}{r-\mu}\right]\left(\frac{x}{X^*}\right)^\alpha & \text{if } X^* < X_g \\ D_g^s(x) & \text{if } X^* \geq X_g \end{cases} \qquad D_b^a(x) = D_b^s(x)$$

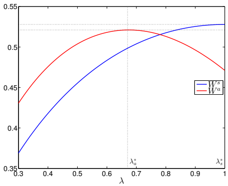
$$W^a(x) = pW_g^a(x) + (1-p)W_b^a(x) \quad \text{where } W_i^a(x) = U_i^a(x) + D_i^a(x)$$



(a) Upstream firm



(b) Downstream firm



(c) Social welfare

Implications on the policies

The innovator suffers losses from information asymmetry while the free rider benefits from it.

- $U_g^a(x) \leq U_g^s(x)$: the deviation from the first-best investment
- $D_g^a(x) \geq D_g^s(x)$: gains from earlier innovation

Perfect protection on patent rights always harms social welfare under asymmetric information (i.e., $\lambda_a^* < 1$).

- The monotonicity does not hold due to the distortion in the investment decision.

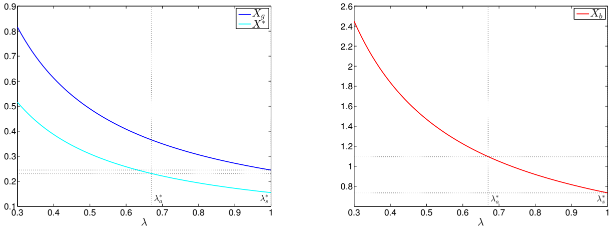
Social welfare is higher under asymmetric information for most of patent protection level.

- The downstream firm's gains from type g's earlier innovation can dominate the losses from type g's inefficient investment.

Given the optimal protection, social welfare is higher under symmetric information (i.e., $W^s(x; \lambda_s^*) \geq W^a(x; \lambda_a^*)$).

- Type g makes an inefficient investment under asymmetric information as long as $X^* < X_g$ holds for λ_a^*.

Effects of information asymmetry on innovation timing



(a) Type g's investment trigger (b) Type b's investment trigger

Information asymmetry always induces the delay of less efficient firms' innovation (i.e., $X_b(\lambda_a^*) > X_b(\lambda_s^*)$).

- Underinvestment in R&D even without the constraints of external financing (cf. Lerner (1999), Hall (2002))

More efficient innovators overinvest if $X^*(\lambda_a) < X_g(\lambda_s^*)(< X_g(\lambda_a^*))$ while underinvest if $X_g(\lambda_s^*) < \min(X^*(\lambda_a^*), X_g(\lambda_a^*))$.

- Overinvestment in R&D in the absence of competition (cf. Miltersen and Schwartz (2004), Hsu and Lambrecht (2007)).

R&D subsidy under symmetric information

Given the subsidy $\eta \in (0, \delta_g)$, R&D costs reduce to $\hat{\delta}_i = \delta_i - \eta$ for $i \in \{g, b\}$, and the firm values are evaluated as

$$\hat{U}_i^s(x) = \left[\frac{\lambda \gamma_i c \hat{X}_i}{r-\mu} - \hat{\delta}_i\right]\left(\frac{x}{\hat{X}_i}\right)^{\alpha}, \quad \hat{D}_i^s(x) = \frac{(\pi - c)x}{r-\mu} + \left[\frac{(1-\lambda)\gamma_i c \hat{X}_i}{r-\mu}\right]\left(\frac{x}{\hat{X}_i}\right)^{\alpha}$$

where

$$\hat{X}_i = \frac{\alpha(r-\mu)\hat{\delta}_i}{(\alpha-1)\lambda\gamma_i c} \tag{11}$$

The government's expenditure is $\hat{S}_i^s(x) = \eta(x/\hat{X}_i)^{\alpha}$, and thus, social welfare in the presence of R&D subsidy is

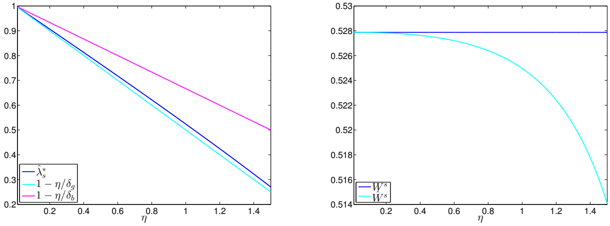
$$\hat{W}^s(x) = p\hat{W}_g^s(x) + (1-p)\hat{W}_b^s(x) \tag{12}$$

where

$$\hat{W}_i^s(x) = \hat{U}_i^s(x) + \hat{D}_i^s(x) - \hat{S}_i^s(x) \tag{13}$$

$$= \frac{(\pi - c)x}{r-\mu} + \left[\frac{\gamma_i c \hat{X}_i}{r-\mu} - \delta_i\right]\left(\frac{x}{\hat{X}_i}\right)^{\alpha} \tag{14}$$

Welfare analysis with R&D subsidy



(a) Optimal patent protection (b) Social welfare

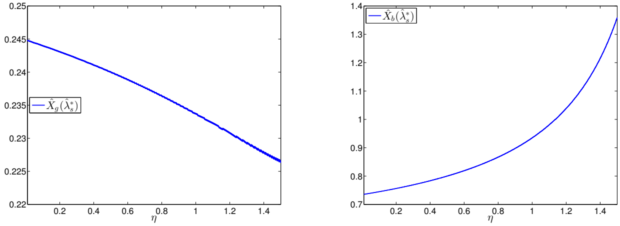
$\hat{\lambda}_s^*(\eta)$ strictly decreases in η and $\hat{\lambda}_s^*(\eta) < 1$ whereas $\lambda_s^* = 1$.

- Given subsidies, perfect patent protection harms social welfare even in the absence of information asymmetry (cf. $\lambda_a^* < 1$).

Social welfare strictly decreases in η and $W^s(x; \lambda_s^*) > \hat{W}^s(x; \hat{\lambda}_s^*)$.

- In maximizing (14), the investment decision $\hat{X}_i$ in (11) is made based on the reduced costs $\hat{\delta}_i$ while the actual costs are δ_i.
- The inefficiency from this disparity can be mitigated by setting $\lambda = 1 - \eta/\delta_i$, but it depends on the firm's type.

Effects of R&D subsidy on innovation timing



(a) Type g's investment trigger (b) Type b's investment trigger

R&D subsidy does not always stimulate innovation.

- Even though the innovation by more efficient firms gets earlier (i.e., $\hat{X}_g(\hat{\lambda}_s^*)$ decreases in η), that of less efficient firms is delayed significantly (i.e., $\hat{X}_b(\hat{\lambda}_s^*)$ increases in η).
- The optimal patent protection is chosen in favor of type g firm (i.e., $\hat{\lambda}_s^*(\eta)$ is closer to $1 - \eta/\delta_g$ than to $1 - \eta/\delta_b$).
- Lach (2002) provided empirical evidence of both positive and negative effects of R&D grants on firms' R&D expenditure.

R&D subsidy under asymmetric information

Given information asymmetry and R&D subsidy, we have

$$\hat{U}_g^a(x) = \begin{cases} \left[\frac{\lambda\gamma_g c\hat{X}^*}{r-\mu} - \hat{\delta}_g\right]\left(\frac{x}{\hat{X}^*}\right)^\alpha & \text{if } \hat{X}^* < \hat{X}_g \\ \hat{U}_g^s(x) & \text{if } \hat{X}^* \geq \hat{X}_g \end{cases} \qquad \hat{U}_b^a(x) = \hat{U}_b^s(x)$$

$$\hat{D}_g^a(x) = \begin{cases} \frac{(\pi-c)x}{r-\mu} + \left[\frac{(1-\lambda)\gamma_g c\hat{X}^*}{r-\mu}\right]\left(\frac{x}{\hat{X}^*}\right)^\alpha & \text{if } \hat{X}^* < \hat{X}_g \\ \hat{D}_g^s(x) & \text{if } \hat{X}^* \geq \hat{X}_g \end{cases} \qquad \hat{D}_b^a(x) = \hat{D}_b^s(x)$$

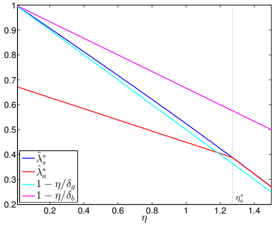
$$\hat{S}_g^a(x) = \begin{cases} \eta\left(\frac{x}{\hat{X}^*}\right)^\alpha & \text{if } \hat{X}^* < \hat{X}_g \\ \hat{S}_g^s(x) & \text{if } \hat{X}^* \geq \hat{X}_g \end{cases} \qquad \hat{S}_b^a(x) = \hat{S}_b^s(x)$$

$$\hat{W}^a(x) = p\hat{W}_g^a(x) + (1-p)\hat{W}_b^a(x) \quad \text{where } \hat{W}_i^a(x) = \hat{U}_i^a(x) + \hat{D}_i^a(x) - \hat{S}_i^a(x)$$

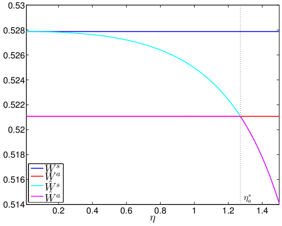
Despite the disparity between $\hat{\delta}_i$ and δ_i, we can preserve the level of social welfare as much as that without the subsidy.

- Type g's investment decision depends on type b's incentive to mimic type g for $\hat{X}^* < \hat{X}_g$ (i.e., $\hat{X}^*$ depends on $\hat{X}_b$).
- We can align $\hat{X}_b(\lambda)$ with $X_b(\lambda_a^*)$ by $\lambda = (1-\eta/\delta_b)\lambda_a^*$, which matches $\hat{X}^*(\lambda)$ with $X^*(\lambda_a^*)$ as well.

Welfare analysis with R&D subsidy



(a) Optimal patent protection



(b) Social welfare

$\hat{W}^a(x;\hat{\lambda}_a^*) = W^a(x;\lambda_a^*)$ holds if $\hat{X}^* < \hat{X}_g$ and $X^* < X_g$ for $\hat{\lambda}_a^*(\eta)$ and λ_a^*, respectively. Otherwise, $\hat{W}^a(x;\hat{\lambda}_a^*) < W^a(x;\lambda_a^*)$ holds.

- If $\hat{X}^* \geq \hat{X}_g$ for $\hat{\lambda}_a^*(\eta)$, $\hat{W}^a(x) = \hat{W}^s(x)$, which decreases in η.
- If $X^* \geq X_g$ for λ_a^*, $W^a(x) = W^s(x)$.

We can find the R&D subsidy η_a^* that makes type g firm's investment timing irrelevant to information structure by solving

$$\frac{\alpha\delta_g - (\alpha-1)\delta_b - \eta_a^*}{\delta_b - \eta_a^*} = \left(\frac{\gamma_b(\delta_g - \eta_a^*)}{\gamma_g(\delta_b - \eta_a^*)}\right)^\alpha \quad (15)$$

Implications on the policies

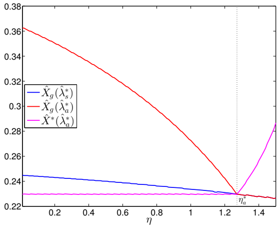
The fact that $\hat{W}^a(x; \hat{\lambda}_a^*)$ does not decrease in η for $\eta \leq \eta_a^*$ can play a crucial role in making policies for multiple industries.

- Suppose there are A and B industries and $\lambda_a^{A*} < \lambda_a^{B*}$ holds.
- The government can maximize social welfare in both industries by setting λ_a^{A*} and granting η_a^B to firms in B industry such that $\hat{\lambda}_a^{B*}(\eta_a^B)$ yields $\hat{W}_B^a(x; \hat{\lambda}_a^{B*}) = W_B^a(x; \lambda_a^{B*})$.
- That is, the R&D subsidy granted to B industry (i.e., η_a^B) needs to be chosen such that $\lambda_a^{A*} = \hat{\lambda}_a^{B*}(\eta_a^B)$ holds.

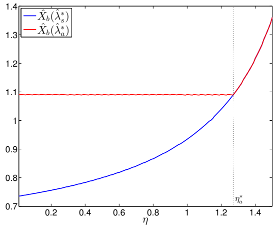
The slope of $\hat{\lambda}_s^*$ is steeper than that of $\hat{\lambda}_a^*$ for $\eta \leq \eta_a^*$.

- For an increment of R&D subsidy, the government should lower less patent protection under asymmetric information.

Effects of R&D subsidy on innovation timing



(a) Type g's investment trigger



(b) Type b's investment trigger

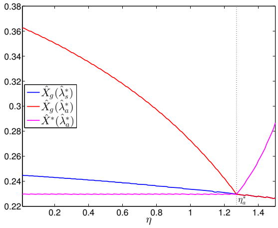
R&D subsidy reduces the inefficiency from information asymmetry.

- The gap between $\hat{X}^*(\hat{\lambda}_a^*)$ and $\hat{X}_g(\hat{\lambda}_a^*)$ decreases in $\eta(\leq \eta_a^*)$.
- The relative difference of R&D cost increases in the amount of subsidy, which makes type b less likely to mimic type g.

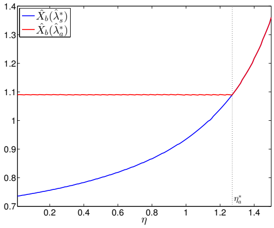
Yet, the timing of actual innovation does not change.

- $\hat{X}^*(\hat{\lambda}_a^*)$ and $\hat{X}_b(\lambda_a^*)$ remain the same for $\eta \leq \eta_a^*$.
- Wallsten (2000) and Klette and Møen (2012) found that the subsidized firms did not raise R&D nor did they cut it back.

Effects of information asymmetry on the innovation



(a) Type g's investment trigger



(b) Type b's investment trigger

Given the subsidy, information asymmetry induces over/under -investment of more/less efficient innovators, respectively (i.e., $\min(\hat{X}_g(\hat{\lambda}_a^*), \hat{X}^*(\hat{\lambda}_s^*)) \leq \hat{X}_g(\hat{\lambda}_s^*)$ and $\hat{X}_b(\hat{\lambda}_a^*) \geq \hat{X}_b(\hat{\lambda}_s^*)$).

- In the absence of subsidy, the effects on type g's innovation is not clear (i.e., either $X^*(\lambda_a^*) < X_g(\lambda_s^*)(< X_g(\lambda_a^*))$ or $X_g(\lambda_s^*) < \min(X^*(\lambda_a^*), X_g(\lambda_a^*))$ can hold).
- Namely, the effects of information asymmetry on innovation timing becomes clearer when R&D subsidy is given.

Conclusion

Contribution of this research

- We clarified how perfect protection aggravates social welfare under asymmetric information based on dynamic investment timing model.
- We showed that social welfare under asymmetric information dominates that under symmetric information for most patent policies, which is a counterintuitive result.
- We found the novel aspects of R&D subsidy in making policies applied to multiple industries.

Future works

- The effects of competition in the downstream market changes the results (cf. preemption)
- Bilateral asymmetry in the information (i.e., upstream firms also cannot observe the true type of downstream firms)