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Patent Infringement and Strategic Trade Policies: R&D and Export Subsidies

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Executive Summary

Given the idea from my previous research that the R&D subsidy issue must be considered with IPR protection, we examine policy choices when a government chooses both R&D subsidies and IPR protection levels simultaneously. Under the circumstance, it will choose a sufficiently weak level of IPR protection that its optimal R&D policy choice will be a subsidy. Hence when both IPR protection and R&D policy choice are modeled, the case for an R&D subsidy remains, but for very different reasons than those of the original strategic R&D subsidy logic. That is, we show that it will be optimal for the domestic government to adopt IPR protection which is sufficiently weak that, in light of this weak IPR protection, it will also want to subsidize the R&D investments of the domestic firm, so as to induce R&D investment of the foreign rival firm to rise as well, which in turn increases the profits of the domestic firm.

Like the original Spencer-Brander result, the R&D incentives that we identify lead governments to set positive R&D subsidies in the non-cooperative equilibrium. However, we find that if exporting governments could cooperate over their policy choices they would continue to subsidize R&D, rather than agreeing to tax R&D as in the original Spencer-Brander setup. The reason is that under cooperation they will also agree to share perfectly the results of R&D investments (i.e., eliminate IPR protection), and R&D subsidies are then required to maintain appropriate incentives for firms to engage in R&D investments. This last result is interesting for two reasons, both of which point to the importance of examining R&D subsidies and IPR

policies in tandem as we have done rather than in isolation as has heretofore typically been done. First, by this result we show that the case for strategic R&D subsidies is more robust than previously thought, as it applies whether exporting governments are acting cooperatively or non-cooperatively, once their equilibrium choices of IPR protection are taken into account as well. And second, by this result we identify a puzzle as to why governments might wish to agree to jointly eliminate, rather than tighten, their levels of IPR protection, given that they have at their disposal R&D subsidy policies to offset the disincentive effects of agreements to share R&D outcomes. We show that the flavor of these findings extend as well to the case in which governments also have export policies at their disposal. In the original Spencer-Brander setup, the addition of export policies leads governments to tax R&D and offer export subsidies, pointing to another way in which the case for strategic R&D subsidies appears to be fragile. But again our results imply that this fragility disappears in a setting in which the choice of IPR protection is modeled as well.

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I. Introduction

Piracy of intellectual property (IP) has emerged as one of most important foreign policy issues for many developed countries, particularly the United States. As we have discussed in my previous work, *Patent Protection and Strategic Trade Policy*, US and IP industry officials have charged that IP piracy in China is costing US firms \$ 2.3 billion in lost trade annually, despite trade agreements in January 1992 and February 1995 that pledged China to improve its IP protection enforcement regime. Baldwin (1988) has pointed out that the US is concerned about these losses, especially "*in view of the increasing competitiveness of other countries as they close the technological and skill gaps that long have been the basis of US cost advantage*". For this reason, the developed countries were insistent during the Uruguay Round that developing countries should adopt appropriate protection for intellectual property rights (IPRs).

Even though the WTO requires member countries to enforce the minimum standards of IPR protection through the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), nations still provide markedly different levels of IPR protection. While many developing countries have had weak or nonexistent IPR laws, use of

trademarks, patents, and copyrights have been common in many developed countries. Given the fact above, widely varying policies on patents, for example, could affect the decisions of firms to engage in research and product development. As we have shown in the previous work, *Patent Protection and Strategic Trade Policy*, IPR protection enforcement regime would affect not only decisions of firms but also other policy decisions of governments. Under the environment that a rival country is loosely enforcing IPR protection, inventive firms cannot perfectly appropriate their new technology and cannot perfectly benefit from their government's R&D subsidies. This country's R&D subsidies could benefit a foreign rival if that foreign country is loosely enforcing IPR protection.

Extending the idea of a previous work, *Patent Protection and Strategic Trade Policy*, this paper extends this research line to a newly proposed analysis where the IPR regime is itself a policy choice that in principle may affect firms' incentives to engage in R&D to the same extent that the choice of an R&D subsidy affects these incentives. Indeed, at an international level IPR protection has been a major focus of negotiations along with R&D subsidies. Thus it is so natural to consider optimal choices for these policies in tandem rather than examining R&D subsidy policy in isolation. In this paper we will show how the role played by these policies is different when the choice of subsidies and IPR protection are modeled in tandem.

The objective of this paper is to examine how strategic trade policies interact, considering IPR policy as a "strategic" trade policy tool. In order to meet this objective, this paper endogenizes the decision process of IPR policy, in which each country chooses the optimal IPR protection enforcement level to maximize its domestic welfare. Given the interdependence of the strategic trade policy tools, each country

will try to set optimally the policies by considering public-good nature of R&D activities. It is well known that an inherent tension exists in the principles of economic efficiency when it comes to arrangements governing the investment in R&D that is required for developing new items. On one hand, discovering, inventing, or creating new things is a private economic activity. Thus inventive firms need to appropriate their knowledge so that they keep undertaking R&D activities. However, once an idea or process has been developed, the marginal cost of an additional use of the idea or process is zero. Efficient allocation of existing knowledge and technology would be achieved by permitting access to it without charge, but such an allocation would damage incentives to invest in any additional R&D activities. This paper shows how each country implements IPR and R&D policies by considering a tension between achieving maximal benefits out of existing knowledge and preserving incentives for innovations and R&D investment.

As Spencer and Brander (1983) showed, an exporting country has an incentive to subsidize R&D activities in the non-cooperative equilibrium. However, we observed in the previous work that previous work on strategic R&D subsidization has proceeded by implicitly assuming that inventive firms have perfect IPRs. Of course in reality the protection of IPRs is not perfect, and the IPR protection enforcement is itself a policy choice that in fact affects not only firms' incentive to invest in R&D but also government's incentive to subsidize R&D activities. By extending the SB model to the IP piracy issue, this paper will show that an exporting country still has an incentive to subsidize R&D activities when it chooses both R&D subsidies and IPR policy simultaneously. In the non-cooperative equilibrium, each exporting country will loosely enforce patent protection so that

domestic firms could copy and use the outcome of the R&D developed in a foreign rival country. Hence when we consider both IPR and R&D policies, the case for an R&D subsidy still remains, but for very different reasons than those of the original strategic R&D subsidy in the SB setup. In the SB model, as a firm's best response to an increase in R&D by its rival is to reduce its own R&D (i.e., R&D reaction curves slope down), the domestic government will wish to subsidize R&D because, in providing the domestic firm with an incentive to do more R&D, the government is able to *discourage* R&D activity by the foreign rival firm, and the *lower* R&D investment of the foreign rival *increases* the profits of the domestic firm. However, when we consider R&D subsidies and IPR protection in tandem, it will turn out that the government will choose a sufficiently weak level of IPR protection so that home and foreign R&D activities are strategic complements. Thus the domestic government will wish to subsidize its firm's R&D in the presence of weak IPR protection, because in providing the domestic firm with an incentive to do more R&D, the government is able to *encourage* R&D activity by the foreign rival firm, and the *greater* R&D investments of the foreign rival *increase* the profits of the domestic firm.

The model will be extended to a cooperative setup where exporting countries cooperate to set both IPR and R&D policies. Under cooperation exporting countries would continue to subsidize R&D activities, rather than agreeing to impose a tax on R&D investment as in the original SB setup. The reason is that under cooperation they will also agree to perfectly share the R&D outcomes developed in both countries by providing no protection on IPRs. Then R&D subsidies are required to maintain appropriate incentives for firms to engage in R&D investments. This result is interesting for two reasons, both of

which point to the importance of examining R&D subsidies and IPR policies in tandem as we have done in this paper rather than in isolation as has heretofore typically been done. First by this result we will show that the case for strategic R&D subsidies is more robust than previously thought, as it applies whether exporting governments are acting cooperatively or non-cooperatively. In other words, when we consider both IPR and R&D policies as strategic trade policy, an exporting country has an incentive to subsidize R&D activities no matter whether or not exporting countries cooperate to set strategic trade policies. Second, by this result we identify a puzzle as to why governments might wish to agree to jointly increase, rather than decrease, their levels of IPR protection, given that they have at disposal R&D subsidy policies to offset the disincentive effects of agreements to share R&D outcomes. This paper will show that the flavor of these findings extends as well to the case in which governments also have export policies at their disposal. In the original SB setup, the addition of export policies leads governments to impose a tax on R&D activities and offer export subsidies, pointing to another way in which the case for strategic R&D subsidies appears to be fragile. However, our result implies that this fragility disappears in a setting in which the choice of IPR protection is modeled as well.

In trying to meet those objectives, this paper basically grafts two past research lines together: strategic trade policy and TRIPS. First, a large number of papers have focused on strategic R&D policy after a pioneer work by Spencer and Brander (1983, hereafter SB) who showed that an exporting country has an incentive to subsidize domestic R&D activities. In contrast with Brander and Spencer (1985), Eaton and Grossman (1986) have pointed out that the result of Brander and Spencer (1985) in case of export subsidies is sensitive to the mode of

competition: price or quantity. However, Bagwell and Staiger (1994) showed that R&D choices are strategic substitutes regardless of the competition mode for the case of stochastic R&D effect on cost. Additionally Maggi (1996) has endogenized the mode of competition introducing capacity constraints. Based on our motivation of this paper, we extend this research line by analyzing the interaction between the trade policy mix: IPR policy and R&D subsidies.

As a pioneer work of the second research line, Chin and Grossman (1988) examined the effect of IPR protection on R&D incentives and social welfare by using a simple north-south model. Diwan and Rodrik (1991) introduced the difference of technological needs and tastes between the north and the south. Extending this research line, Taylor (1993) examined how a reduction in southern patent protection raises northern incentives to other barriers to imitations. Additionally Taylor (1994) explored the link between IP protection and growth by considering the ability of firms to transfer technologies. Incorporating the subsidy issue into this research line, this paper sheds light on the effect of IPR protection on R&D policy. Moreover, this paper takes steps further than the above work, endogenizing the decision process of IPR policy.

The rest of this paper proceeds as follows. Section II establishes the basic theoretical model that is based on the SB model, and explores economic incentives facing countries that choose R&D subsidies at the Nash setup. Then we provide policy implications considering interaction between trade policy tools: R&D subsidies and IPR policy. This section also explores the case where exporting countries cooperate to set strategic trade policy. Section III considers an additional trade policy tool – export subsidies – over both Nash and cooperative cases. Section IV extends the basic model to the North-South model in order

to consider the North-South IPR disputes and then provides policy implications. Section V then concludes.

II. The Model

A. The Basic Setup

We present in this section our basic framework. Basically the model is very similar to one in the previous work, *Patent Protection and Strategic Trade Policy*. However, we consider IPR policy as an endogenous policy tool, while in the previous work it was taken as exogenous. Following the SB model, we assume that there are two exporting countries and a third importing country. One exporting country will be referred to as the home (no *) country, while the other is called the foreign (*) country. Each exporting country has a single exporting firm. It is assumed that both firms produce a homogenous good and compete in a third market by setting quantity (Cournot competition). Basically this model is based on a three-stage game where two exporting firms and two governments play.

The Basic Game:

Policy Stage: Both home and foreign governments simultaneously choose an R&D subsidy rate and patent protection enforcement level.

R&D Stage: Observing the R&D subsidy and enforcement levels of each government, each firm simultaneously chooses R&D investment level.

Output Stage: Observing the R&D subsidy and enforcement levels of each government and R&D investment levels of each firm, each firm simultaneously chooses output level.

A domestic firm produces output y at cost C , which includes all

costs except R&D, and earns revenue R . The R&D level of this domestic firm is denoted x and costs v per unit. The government provides R&D subsidies (tax if negative) at a rate of s . Profits of this firm are then given as follows:

$$(1) \quad \pi(y, y^*, x, x^*, \theta, s) \equiv R(y, y^*) - C(y, x, x^*, \theta) - (v - s)x.$$

Outputs y and y^* are substitutes and it is assumed that an increase in the foreign output reduces the marginal revenue of the domestic firm. Using subscripts to denote partial derivatives, we interpret the assumption as follows:

$$(2) \quad R_y > 0; \quad R_{y^*} < 0; \quad R_{yy^*} < 0.$$

We differ from the SB model in assuming that the foreign (domestic) firm's R&D outcome could affect the domestic (foreign) firm's marginal cost if the home (foreign) country is loosely enforcing patent protection. The production cost of a domestic firm depends on domestic output level, domestic and foreign R&D levels, and the home country's IPR policy: $C(y, x, x^*, \theta) = yc(x, x^*, \theta)$, where $c > 0$ is marginal cost. Each firm has the following marginal cost:¹⁾

$$(3) \quad c(x, x^*, \theta) \equiv \alpha + c^1(x) + \theta c^2(x^*); \quad c^*(x, x^*, \theta^*) \equiv \alpha + c^{1*}(x^*) + \theta^* c^{2*}(x),$$

where α is sufficiently large so that marginal cost is non-negative for all R&D investment levels. Let θ and θ^* be patent protection enforcement levels of home and foreign country, respectively. They

1) For simplicity, we assume $c_{xx^*} = c_{x^*x} = 0$.

are defined between 0 and 1. The home government is perfectly enforcing patent protection if $\theta=0$, while it provides no protection on patents and thus the domestic firm can freely copy the foreign firm's R&D outcome if $\theta=1$. For simplicity, we assume *potential* effects of any increase in domestic R&D investment on domestic and foreign marginal costs are the same: $c_x \equiv c_x^{1*} = c_x^{2*} < 0$ and $c_{xx^*} = c_{x^*x}^* = 0$. In other words, domestic R&D investment could *potentially* reduce the foreign marginal cost at the same extent that it reduces the domestic marginal cost. However, the *actual* effects depend on the foreign country's IPR protection enforcement level: $dc^*/dx = \theta^* c_x^{2*}$. When both countries are perfectly enforcing IPR protection ($\theta = \theta^* = 0$), this model goes back to the SB setup. Additionally the rate of decrease is assumed to decline as R&D investment increases: $c_{xx} > 0$ and $c_{x^*x^*}^* > 0$. It is also assumed that the domestic marginal cost is decreasing when the home country's IPR protection enforcement is getting weaker given home and foreign R&D activities:

$$(4) \quad c_\theta = c^2 < 0; \quad c_\theta^* = c^{2*} < 0; \quad c^1, c^{1*} < 0.$$

The idea of backward induction helps to find a subgame perfect equilibrium. Thus we start by solving for the optimal choice of firms over each possible situation, and then work backward to compute the optimal choice for governments before. Then the equilibrium output levels will be calculated in the last stage, R&D levels in the second stage, and the optimal policy in the first stage. The Nash equilibrium output levels maximizing profits are characterized by the first-order condition: $\pi_y = R_y - c(x, x^*, \theta) = 0$ and the second-order condition: $\pi_{yy} = R_{yy} < 0$. Then we obtain the equilibrium output levels by solving the first-order conditions for output levels:

$$(5) \quad y = q(x, x^*, \theta, \theta^*); \quad y^* = q^*(x, x^*, \theta, \theta^*).$$

Totally differentiating the first-order conditions with respect to y and y^* , we can show the slope of the *output* reaction function, which is negative from (2) and the second-order conditions:

$$(6) \quad \text{Home} \quad \frac{dy}{dy^*} = -\frac{R_{yy^*}}{R_{yy}} < 0; \quad \text{Foreign} \quad \frac{dy^*}{dy} = -\frac{R_{y^*y}}{R_{y^*y^*}} < 0.$$

Thus each firm's *output* reaction curve is downward sloping because outputs are substitutes. However, effects of each R&D activities on output levels depend on each country's patent protection enforcement level:

$$(7) \quad q_x = \frac{c_x(R_{y^*y^*} - \theta^* R_{yy^*})}{A} > 0; \quad q_x^* = \frac{c_x(\theta^* R_{yy} - R_{y^*y})}{A};$$

$$(8) \quad q_{x^*} = \frac{c_{x^*}(\theta R_{y^*y^*} - R_{yy^*})}{A}; \quad q_{x^*}^* = \frac{c_{x^*}(R_{yy} - \theta R_{y^*y})}{A} > 0,$$

where $A \equiv R_{yy} R_{y^*y^*} - R_{yy^*} R_{y^*y} > 0$ as a stability condition. Notice that when both countries are perfectly enforcing patent protection ($\theta = \theta^* = 0$), these effects are equal to the result of the original SB model. As results of the SB model, domestic (foreign) R&D activities are always good for domestic (foreign) output level. However, the result of the cross effects contrasts interestingly with that of the SB model. In the SB case, the cross effects q_{x^*} and q_x^* are negative, but with patent infringement q_{x^*} (q_x^*) is positive if $\theta > R_{yy^*} / R_{y^*y^*}$ ($\theta^* > R_{y^*y} / R_{yy}$). In other words, home (foreign) R&D activities are good for foreign (home) output level if foreign (home) country is *loosely* enforcing patent

protection.

Additionally the effects of IPR policy on output levels can be obtained by total differentiation of the first order conditions $\pi_y = R_y - c(x, x^*, \theta) = 0$ and $\pi_{y^*} = R_{y^*} - c^*(x, x^*, \theta^*) = 0$ to obtain the following comparative static matrix equation:

$$(9) \begin{bmatrix} R_{yy} & R_{yy^*} \\ R_{y^*y} & R_{y^*y^*} \end{bmatrix} \begin{bmatrix} y_\theta \\ y_\theta^* \end{bmatrix} = \begin{bmatrix} c_\theta \\ 0 \end{bmatrix}$$

Using (9), we can show the effects of IPR policy on output levels as follows:

$$(10) \quad y_\theta = \frac{c_\theta R_{y^*y^*}}{A} > 0; \quad y_\theta^* = -\frac{c_\theta R_{y^*y}}{A} < 0; \quad y_{\theta^*} = -\frac{c_{\theta^*} R_{yy^*}}{A} < 0; \quad y_{\theta^*}^* = \frac{c_{\theta^*} R_{yy}}{A} > 0.$$

Holding others fixed, home country's weak enforcement is good for the domestic firm's production but bad for the foreign firm's production. The reason is that the weak IPR protection of the home country will provide cost advantage for the domestic firm because it drops the domestic marginal cost. However, for the total effect of IPR policy on output, we need to consider the effects on R&D investment: $dy/d\theta = y_x x_\theta + y_{x^*} x_\theta^* + y_\theta$.

We now analyze the preceding stage, R&D stage, in which firms choose R&D levels maximizing their own profits. Firms are aware of the dependence of output on R&D levels. Then profits can be rewritten as functions of x and x^* . Let G represent the profit function for the domestic firm:

$$(11) \quad \begin{aligned} G(x, x^*, \theta, \theta^*, s) &\equiv \pi(q(x, x^*, \theta, \theta^*), q^*(x, x^*, \theta, \theta^*), x, x^*, \theta, s) \\ &= R(q(x, x^*, \theta, \theta^*), q^*(x, x^*, \theta, \theta^*)) - q(x, x^*, \theta, \theta^*)c(x, x^*, \theta) - (v - \bar{s})x \end{aligned}$$

The Nash equilibrium R&D levels are characterized by the first-order conditions: $G_x = R_{q^*} q_x^* - q c_x - (v - s) = 0$ and the second-order conditions: $G_{xx} < 0$. Then the solutions to the first-order conditions can be written as a function of strategic trade policy tools:

$$(12) \quad x = z(s, s^*, \theta, \theta^*); \quad x^* = z^*(s, s^*, \theta, \theta^*).$$

Totally differentiating the first-order conditions, we can show the slope of the R&D reaction curve as follows:

$$(13) \quad \text{Home} \quad \frac{dx}{dx^*} = -\frac{G_{xx^*}}{G_{xx}}; \quad \text{Foreign} \quad \frac{dx^*}{dx} = -\frac{G_{x^*x}}{G_{x^*x^*}}.$$

The key difference between this modification and the SB model is that each country's IPR policy affects the slopes of the R&D reaction curve. While home and foreign R&D activities are strategic substitutes in the SB model, the relationship in this modification depends on both countries' patent protection regimes. Using (8), we can show that the sign of G_{xx^*} depends on the home country's IPR protection enforcement level: $G_{xx^*} = (R_{q^*q} q_{x^*} + R_{q^*q^*} q_{x^*}^*) q_x^* - q_{x^*} c_x$. If both countries are loosely enforcing IPR protection, the R&D reaction curves are upward sloping, implying that home and foreign R&D activities are strategic complements rather than strategic substitutes.

Totally differentiating the first-order conditions of the profit maximization with respect to x , x^* , and s , we obtain the following comparative static matrix equation:

$$(14) \begin{bmatrix} G_{xx} & G_{xx^*} \\ G_{x^*x} & G_{x^*x^*} \end{bmatrix} \begin{bmatrix} x_s \\ x_s^* \end{bmatrix} = \begin{bmatrix} -1 \\ 0 \end{bmatrix}.$$

Using (14), we can show the effects of R&D subsidies on R&D investment as follows:

$$(15) \quad x_s = -\frac{G_{x^*x^*}}{B} > 0; \quad x_s^* = \frac{G_{x^*x}}{B}; \quad x_{s^*} = \frac{G_{xx^*}}{B}; \quad x_{s^*}^* = -\frac{G_{xx}}{B} > 0,$$

where $B \equiv G_{xx} G_{x^*x^*} - G_{xx^*} G_{x^*x} > 0$. Notice that the domestic (foreign) R&D subsidies are good for the foreign (home) R&D investment ($x_s^*, x_s > 0$) when the home and foreign R&D activities are strategic complements ($G_{xx^*}, G_{x^*x} > 0$). Strategic complementarity occurs when both exporting countries are loosely enforcing IPR protection. Notice that the effect of the domestic (foreign) R&D activities on foreign (home) output level is positive when foreign (home) country's IPR protection is sufficiently weak [see (7) and (8)]. Favorable R&D activities over countries make the sign of (G_{xx^*}, G_{x^*x}) positive, implying that they are strategic complements. See my previous research, *Patent Protection and Strategic Trade Policy*, for the main results of the last two stages.

Now we are ready to analyze each country's strategic trade policy mix focusing on the first stage. First we will look at the Nash equilibrium and then move to the case where both exporting countries cooperate to set trade policy mix: R&D subsidies and IPR protection enforcement.

B. Nash Equilibrium

We assume that each government maximizes the domestic welfare that is the domestic firm's profits less R&D subsidy costs.

$$(P1) \max_{s, \theta} W(s, s^*, \theta, \theta^*) \equiv G(z(s, s^*, \theta, \theta^*), z^*(s, s^*, \theta, \theta^*), \theta, \theta^*, s) - sz(s, s^*, \theta, \theta^*).^{2)}$$

The first-order conditions are given as follows:

$$(16) \quad G_z z_s + G_z z_s^* + G_s - z - sz_s = 0;$$

$$(17) \quad G_z z_\theta + G_z z_\theta^* + G_\theta - sz_\theta = 0.$$

Since $G_z = 0$, $G_s = z$, and $z_s^*/z_s = dx^*/dx$ from (15), one can show that the optimal R&D subsidies are given as follows:

$$(18) \quad s = G_z \frac{dx^*}{dx}.$$

This optimal R&D subsidy rate is dependent on the IPR protection enforcement levels over countries, θ and θ^* , because θ determines the sign of externalities and θ^* does the slope of the foreign R&D reaction curve. Since $G_z = 0$, and $G_\theta = R_q q_\theta + R_{q^*} q_\theta^* - q_\theta c - qc_\theta = R_{q^*} q_\theta^* - qc_\theta$, one can rewrite (17) as follows:

$$(19) \quad G_z \left(z_\theta^* - \frac{dx^*}{dx} z_\theta \right) + R_{q^*} q_\theta^* - qc_\theta = 0.$$

Solving the equation (19) for θ , one can show the following Nash equilibrium.

2) Actually this optimization problem has a constraint function: $0 \leq \theta \leq 1$. We check both corner solutions by checking the sign of W_θ . Please see Appendix A for details.

Nash Equilibrium with 2 instruments: R&D Subsidies and IPR Policy³⁾

$$\frac{R_{yy}R_{y^*}}{R_{y^*y}R_{y^*} + yA} < \theta < 1; \quad s = G_x \cdot \frac{dx^*}{dx} > 0.$$

This result of the Nash equilibrium that we found here contrasts interestingly with those developed by Spencer and Brander (1983). Even though each exporting country still has an incentive to subsidize its domestic R&D activities, the logic behind is different from that of the SB model. In Spencer and Brander (1983), the R&D game exhibits negative externalities and the foreign R&D reaction curve is negatively sloped implying that home and foreign R&D activities are strategic substitutes. As a firm's best response to an increase in R&D by its rival is to reduce its own R&D (i.e., R&D reaction curves slope down). The domestic government will wish to subsidize R&D because, in providing the domestic firm with an incentive to do more R&D, the government is able to *discourage* R&D activity by the foreign rival firm, and the *lower* R&D investment of the foreign rival firm *increases* the profits of the domestic firm. However, in our setup with IPR policy, it will be optimal for the domestic government to adopt IPR protection which is sufficiently weak that, in light of this weak IPR protection, it will also want to subsidize the R&D investments of the domestic firm, so as to induce R&D investment of the foreign rival firm to rise as well, which in turn increases the profits of the domestic firm.

At the Nash equilibrium, there is a positive externality in the R&D game and the foreign R&D reaction curve is positively sloped

3) See Appendix A for calculation. We leave most of the mathematical details to the appendices, and concentrate on the general story.

implying that home and foreign R&D activities are strategic complements. The positive externalities and strategic complementarity come from the fact that each exporting country has an incentive to free ride on the rival's R&D outcome: $\frac{R_{yy} R_{y^*}}{R_{y^*y} R_{y^*} + yA} < \theta < 1$. Since both countries have an incentive to loosely enforce IPR protection, the rival's R&D activities are good for the inventive firm's profits: $G_{z^*} > 0$ and home and foreign R&D activities are complements rather than substitutes: $G_{zz^*}, G_{z^*z} > 0$.⁴ The free rider problem stems from public-good nature of R&D activity: (1) its stock does not diminish with its consumption and (2) the marginal cost of an additional use of the idea or process is almost zero. For these reasons, each country has an incentive to be a free rider on the rival's R&D outcome. From Appendix 2-A, it couldn't be equilibrium for the government to perfectly allow its national firm to copy the outcome of the rival's R&D activities ($\theta=1$) because weak enforcement will hurt its national firm's incentive to invest in R&D activities.⁵ Rather, under the weak IP protection regime the firm will try to free ride on the rival's R&D outcome. Thus the Nash equilibrium IPR policy requires balancing these two effects. We now summarize our findings for the Nash equilibrium:

Proposition 1 Nash Equilibrium with 2 instruments

At the Nash Equilibrium, each exporting country has an incentive to free ride on the rival's R&D outcome by loosely enforcing IPR protection. Exporting countries also have an incentive to subsidize their domestic R&

4) Positive externalities guarantee strategic complementarity when the demand for the final good is convex. Please see Proposition 6 in my previous work, *Patent Protection and Strategic Trade Policy*.

5) See Appendix A. The corner solution of ($\theta=1$) violates the slackness condition.

D activities. In contrast with Spencer and Brander, the R&D game exhibits positive externalities and R&D reaction curves are upward sloping, implying that home and foreign R&D activities are strategic complements.

C. The Jointly Optimal Policy Choices among Exporting Countries

Now suppose that both exporting countries cooperate to set the trade policy mix: R&D subsidies and IPR policy in order to maximize the sum of both countries' welfare:

$$(P2) \max_{s, s^*, \theta, \theta^*} W(s, s^*, \theta, \theta^*) + W^*(s, s^*, \theta, \theta^*). \quad 6)$$

The first-order conditions are given as follows:

$$(20) \quad G_z z_s + G_z z_s^* + G_s - z - s z_s + G_z^* z_s - s^* z_s^* = 0;$$

$$(21) \quad G_z z_\theta + G_z z_\theta^* + G_\theta - s z_\theta + G_z^* z_\theta + G_z^* z_\theta^* - s^* z_\theta^* = 0.$$

Solving (20) and the condition of the foreign country analogous to (20) for s and s^* and using (21), we can show the jointly optimal policy choices:

Joint Optimum with 2 instruments: R&D Subsidies and IPR Policy⁷⁾

$$\theta = \theta^* = 1; \quad s = G_z^* > 0; \quad s^* = G_z > 0.$$

We find that if exporting countries could cooperate over their policy

6) The point that we talked about in footnote 2 applies, too.

7) See Appendix B.

choices, they would continue to subsidize R&D, rather than agreeing to impose a tax on R&D activities as in the original SB setup. The reason is that under cooperation they will agree to share perfectly the results of R&D investments (i.e., eliminate IPR protection), and R&D subsidies are then required to maintain appropriate incentives for firms to engage in R&D investments. This result contrasts interestingly with that of Spencer and Brander (1983). Even though the SB model has the same formula of the jointly optimal R&D subsidies with ours, the signs are different. While in the SB model the R&D game exhibits negative externalities, positive externalities occur when both countries provide no IPR protection. Governments will consider strategic externalities in this R&D game ($s = G_z^*$, $s^* = G_{z^*}$), but there were negative externalities in the SB model while positive externalities in our setup. We now summarize our findings for the jointly optimal policy choices:

Proposition 2 Joint Optimum with 2 instruments

When both exporting countries cooperate to set strategic policy instruments in order to maximize the joint welfare, they will continue to subsidize R&D activities, rather than agreeing to impose a tax on R&D investment as in the standard SB model. The reason is that under cooperation both countries will perfectly share R&D outcome and then R&D subsidies are required to maintain appropriate incentives for firms to engage in R&D investment.

This result is interesting for two reasons, both of which point to the importance of examining R&D subsidies and IPR policies in tandem as this paper has done rather than in isolation as has heretofore typically been done. First, by this result we show that the case for strategic R&D subsidies is more robust than previously thought, as it applies whether exporting countries are acting cooperatively or non-

cooperatively, once their equilibrium choices of IPR protection are taken into account as well. And second, by this result we identify a puzzle as to why governments might wish to agree to jointly increase, rather than decrease, their levels of IPR protection, given that they have at their disposal R&D subsidy policies to offset the disincentive effects of agreements to share R&D outcomes. In the next section, we will analyze how an addition of export subsidies affects this result.

III. Export Subsidies, R&D Subsidies and IPR Policy

Now let us consider the third instrument of industrial strategic policy, an export subsidy. Each exporting country is assumed to set export subsidies in the policy stage: the first stage. Observing the R&D and export subsidies and IPR protection enforcement levels of each government, each firm then chooses R&D investment at the second stage, output at the third stage. Following the previous analysis, we will first look at the Nash equilibrium and then move to the case where both exporting countries cooperate to set strategic trade policy instruments: export and R&D subsidies and IPR policy.

A. Nash Equilibrium

The profit function of the domestic firm is then given as follows:

$$(22) \quad \pi(y, y^*, x, x^*, e, \theta) = R(y, y^*) - C(y, x, x^*, \theta) - (v-s)x + ey, \quad (22)$$

where the export subsidy is denoted e . The Nash equilibrium output levels maximizing profits are characterized by the first-order condition: $\pi_y = R_y - c(x, x^*, \theta) + e = 0$ and the second-order condition: $\pi_{yy} = R_{yy} < 0$. The solutions to the profit maximization problems are:

$$(23) \quad y = q(x, x^*, e, e^*, \theta, \theta^*); \quad y^* = q^*(x, x^*, e, e^*, \theta, \theta^*).$$

Totally differentiating the first-order conditions with respect to y, y^* , and e , we obtain the following comparative static matrix equation:

$$(24) \begin{bmatrix} R_{yy} & R_{yy^*} \\ R_{y^*y} & R_{y^*y^*} \end{bmatrix} \begin{bmatrix} y_e \\ y_e^* \end{bmatrix} = \begin{bmatrix} -1 \\ 0 \end{bmatrix}$$

Using (24), we show the effects of export subsidies on output levels as follows:

$$(25) \quad y_e = -\frac{R_{y^*y^*}}{A} > 0; \quad y_e^* = \frac{R_{y^*y}}{A} < 0; \quad y_e = \frac{R_{yy^*}}{A} < 0; \quad y_e^* = -\frac{R_{yy}}{A} > 0.$$

Holding others fixed, the home country's export subsidies are good (bad) for the domestic (foreign) output production. However, for the total effect of the export subsidy on output, we must consider effects on R&D investment: $dy/de = y_x x_e + y_x^* x_e^* + y_e$.

Actually there is not much difference between the R&D-stage analysis with the export subsidies and the analysis without them. The only difference is the equilibrium R&D investment levels. They are a function of export subsidies as well as R&D subsidies and IPR protection enforcement:

$$(26) \quad x = z(s, s^*, e, e^*, \theta, \theta^*); \quad x^* = z^*(s, s^*, e, e^*, \theta, \theta^*).$$

Now we are ready to analyze the policy stage in which both countries simultaneously choose 3 policy instruments: R&D and export subsidies and IPR protection enforcement level. We assume again that each government maximizes the domestic welfare, which is the domestic firm's profits less R&D and export subsidy costs:

$$(P3) \quad \max_{s, e, \theta} W(s, s^*, e, e^*, \theta, \theta^*) \equiv G(z(s, s^*, e, e^*, \theta, \theta^*), z^*(s, s^*, e, e^*, \theta, \theta^*), \theta, \theta^*, s, e) - sz(s, s^*, e, e^*, \theta, \theta^*) - eq(z, z^*, e, e^*, \theta, \theta^*)$$

The first-order conditions are given as follows:

$$(27) \quad G_z z_s + G_z z_s^* + G_s - z - sz_s - e(q_z z_s + q_z z_s^*) = 0;$$

$$(28) \quad G_z z_e + G_z z_e^* + G_e - sz_e - q - e(q_z z_e + q_z z_e^* + q_e) = 0;$$

$$(29) \quad G_z z_\theta + G_z z_\theta^* + G_\theta - sz_\theta - e(q_z z_\theta + q_z z_\theta^* + q_\theta) = 0.$$

Since $G_z = 0$, $G_s = z$ and $z_s^*/z_s = dx^*/dx$ from (15), one can show that the optimal R&D subsidy rate is given:

$$(30) \quad s = G_z \frac{dx^*}{dx} - e \left(q_z + q_z \frac{dx^*}{dx} \right).$$

Plugging (30) into (28) and rearranging, we obtain the optimal R&D and export subsidy rates and we can also show the optimal IPR protection enforcement level in the Nash setup by plugging the optimal R&D and export subsidies into (29):

Nash Equilibrium with 3 instruments: R&D and Export Subsidies and IPR Policy⁸⁾

$$\frac{R_{yy^*}}{R_{yy}} < \theta < 1; \quad s = \frac{G_z \frac{dx^*}{dx} \left(q_z - \frac{dy^*}{dy} q_z \right) - R_q q_z \frac{dy^*}{dy} \frac{dx^*}{dx}}{q_z \frac{dy^*}{dy} \frac{dx^*}{dx} + q_z} > 0;$$

$$e = \frac{\frac{dy^*}{dy} \left(G_z \frac{dx^*}{dx} + R_q q_z \right)}{q_z \frac{dy^*}{dy} \frac{dx^*}{dx} + q_z} < 0.$$

8) See Appendix C for calculation.

The optimal IPR protection enforcement level shows that each exporting country has an incentive to free ride on the rival's R&D outcome. In striking contrast with Spencer and Brander (1983), signs of R&D and export subsidies are opposite: Each exporting country has incentives to subsidize R&D activities but to impose a tax on exports. Since each country is loosely enforcing IPR protection at the Nash equilibrium, weak enforcement damages each inventive firm's incentive to invest in R&D activities. To cure the damaged incentives, each government must subsidize its domestic R&D activities. However, due to R&D subsidization and positive externalities that have arisen at the Nash setup both exporting countries overproduce output. To cure this overproduction, each country has an incentive to impose a tax on exports. This result implies that the robustness of strategic R&D subsidies extends as well to the case in which governments also have export subsidies at their disposal. In the standard SB model, the addition of export subsidies leads governments to impose a tax on R&D activities and to subsidize exports, implying the strategic R&D subsidies are fragile. However, when we consider IPR policy as well as R&D and export subsidies, this fragility disappears. We now summarize our findings for the Nash equilibrium with 3 instruments:

Proposition 3 Nash Equilibrium with 3 Instruments

When exporting countries can use R&D and export subsidies and IPR policy as strategic trade policy, the robustness of strategic R&D subsidies still holds. They have an incentive to free ride on the rival's R&D outcome at the Nash equilibrium and also subsidize R&D activities in order to cure the firms' damaged incentives to invest in R&D activities due to weak IPR protection. However, they will impose a tax on exports.

B. Jointly Optimal Policy Choices

Now let us consider the case where both exporting countries cooperate to set strategic trade policy tools in order to maximize the joint welfare. Their optimization problem is then:

$$(P4) \quad \max_{s, s^*, e, e^*, \theta, \theta^*} W(s, s^*, e, e^*, \theta, \theta^*) + W^*(s, s^*, e, e^*, \theta, \theta^*) \quad 9)$$

The first-order conditions are given as follows:

$$(31) \quad G_z z_s + G_z z_s^* + G_s - z - sz_s - e(q_z z_s + q_z z_s^*) + G_z^* z_s - s^* z_s^* - e^*(q_z^* z_s + q_z^* z_s^*) = 0;$$

$$(32) \quad G_z z_e + G_z z_e^* + G_e - sz_e - e(q_z z_e + q_z z_e^* + q_e) + G_z^* z_e + G_z^* z_e^* + G_e^* - s^* z_e^* - e^*(q_z^* z_e + q_z^* z_e^* + q_e^*) = 0;$$

$$(33) \quad G_z z_\theta + G_z z_\theta^* + G_\theta - sz_\theta - e(q_z z_\theta + q_z z_\theta^* + q_\theta) + G_z^* z_\theta + G_z^* z_\theta^* - s^* z_\theta^* - e^*(q_z^* z_\theta + q_z^* z_\theta^* + q_\theta^*) = 0$$

Solving these equations for the policy tools, we can show the following equilibrium:

Joint Optimum with 3 instruments: Export and R&D Subsidies and IPR Policy¹⁰⁾

$$\theta = 1; \quad s = -R_q q_z^* - \theta^* q^* c_z^* > 0; \quad e = R_q^* < 0.$$

Again, it turns out that both exporting countries will perfectly share

9) The point that we talked about in footnote 2 applies, too.

10) See Appendix D for calculation.

R&D outcome by allowing their firms to *freely* copy the rival's R&D outcome. In addition, both countries have an incentive to subsidize for the same reason with the case of 2 instruments: R&D subsidies will cure the inventive firms' damaged incentive to invest in R&D activities.

In striking contrast with the previous case, R&D investment is *jointly* efficient when exporting countries cooperate to set the strategic trade policies: R&D and export subsidies and IPR policy. In other words, both firms minimize the joint costs when both countries cooperate to set the strategic trade policy. The condition for the joint cost minimization is given as follows:¹¹⁾

$$(34) \quad yc_x - v + \theta^* q^* c_z^* = 0.$$

Without R&D subsidies, we can show that firms under-invest in R&D activities: $yc_x - v + \theta^* q^* c_z^* = R_{q^*} q_x^* + \theta^* q^* c_z^* < 0$ by using the first-order condition of the R&D stage: $R_{q^*} q_x^* - yc_x - v = 0$. It turns out that the jointly optimal R&D subsidies satisfy the condition (34), restoring the joint efficiency of R&D investment. It was shown in Spencer and Brander (1983) that at the *Nash* equilibrium R&D investment efficiency is achieved when exporting countries can use both R&D and export subsidies. The reason is that exporting countries have two instruments to control both output and R&D effects on the welfare. In the SB model, R&D should be taxed. The R&D tax is exactly as required to undo the R&D bias and restores *domestic* R&D investment efficiency. However, we must consider the *joint* efficiency

11) We can obtain this condition solving the joint cost minimization problem:

$$\min C - vx + C^* - vx^*.$$

of R&D investment when home and foreign R&D activities interact through weak IP protection regime. That's why the joint efficiency is achieved when both exporting countries cooperate to set strategic trade policy. In other words, for the joint efficiency to be achieved, the jointly optimal R&D subsidies must consider the cross effect that domestic R&D activities have on the foreign firm's marginal cost. This is exactly what the second term of the optimal R&D subsidy rate implies. Therefore the R&D subsidization that maximizes the joint welfare restores the *joint* efficiency of R&D investment.

However, the optimal export subsidies are negative, implying that each country needs to impose a tax on exports. The reason is that each exporting country needs to consider the negative effect of its production on the rival's production. The export tax is exactly as required to offset the negative effect of production on the rival's revenue. We now summarize our findings for the jointly optimal policy choices:

Proposition 4 Joint Optimum with 3 Instruments

Each exporting country will cooperate to perfectly share R&D outcome and have an incentive to impose a tax on exports in order to offset the negative effect of production rivalry. However, R&D should be subsidized because weak IP protection enforcement damages firms' incentive to invest in R&D activities. The R&D subsidy is exactly as required to restore joint efficiency of R&D investment.

IV. Patent Infringement as North-South Confrontation

In reality, IPR disputes are involved a North-South confrontation rather than a North-North dispute. Because of the IP piracy in some developing countries, northern inventive firm cannot perfectly appropriate their new technology. In this section, we introduce this North-South confrontation by interpreting the third importing country as a southern country. The southern country is assumed to produce the homogenous good that northern firms do, but not to invest in R&D activities. Instead, the southern firm could copy the northern firm's R&D outcome if the Southern country is loosely enforcing IP protection. It is still assumed that every consumer is located in the southern country. Then three firms' profit functions are defined as follows:

$$(35) \quad \text{Home: } \pi(y, y^*, y', x, x^*, \theta, s, e) \equiv R(y, y^*, y') - y c(x, x^*, \theta) - (v - s)x + ey$$

$$\text{Foreign: } \begin{aligned} & \pi^*(y, y^*, y', x, x^*, \theta^*, s^*, e^*) \\ & \equiv R^*(y, y^*, y') - y^* c^*(x, x^*, \theta^*) - (v - s^*)x^* + e^* y^* \end{aligned}$$

$$\text{South: } \pi'(y, y^*, y', x, x^*, \theta, s) \equiv R'(y, y^*, y') - y' c'(x', \theta'),$$

where the southern (imitating) firm's output is denoted y' , R&D level x' which is determined by the Southern country's IP protection enforcement level as follows:

$$(36) \quad x' \equiv \theta' \max\{x, x^*\}.$$

The Nash equilibrium output levels maximizing profits are characterized by the first-order conditions: $\pi_y = R_y - c(x, x^*, \theta) + e = 0$, $\pi_{y^*} = R_{y^*} - c^*(x, x^*, \theta^*) + e^* = 0$, and $\pi_{y^I} = R_{y^I} - c^I(x, x^*, \theta^I) = 0$. The solutions to the profit maximization problems are given as follows:

$$(37) \quad y = q(x, x^*, e, e^*, \theta, \theta^*, \theta^I); \quad y^* = q^*(x, x^*, e, e^*, \theta, \theta^*, \theta^I);$$

$$y^I = q^I(x, x^*, e, e^*, \theta, \theta^*, \theta^I).$$

Totally differentiating the first-order conditions, we obtain slopes of the output reaction curves:

$$(38)$$

$$\text{Home: } \frac{dy}{dy^*} = \frac{-R_{yy}R_{y^I y^I}^I + R_{yy^I}R_{y^I y^*}^I}{A_2} < 0; \quad \frac{dy}{dy^I} = \frac{-R_{yy^I}R_{y^* y^*}^* + R_{yy^*}R_{y^* y^I}^*}{A_1} < 0;$$

$$\text{Foreign: } \frac{dy^*}{dy} = \frac{-R_{y^* y^*}^* R_{y^I y^I}^I + R_{y^* y^I}^* R_{y^I y^*}^I}{A_3} < 0; \quad \frac{dy^*}{dy^I} = \frac{-R_{yy^I}R_{y^* y^*}^* + R_{yy^*}R_{y^* y^I}^*}{A_1} < 0;$$

$$\text{South: } \frac{dy^I}{dy} = \frac{-R_{y^* y^*}^* R_{y^I y^I}^I + R_{y^* y^I}^* R_{y^I y^*}^I}{A_3} < 0; \quad \frac{dy^I}{dy^*} = \frac{-R_{yy^I}R_{y^I y^I}^I + R_{yy^*}R_{y^I y^*}^I}{A_2} < 0,$$

where $A_1 \equiv R_{yy^*}R_{y^* y^I}^* - R_{yy^I}R_{y^I y^*}^I > 0$, $A_2 \equiv R_{yy^I}R_{y^I y^*}^I - R_{yy^*}R_{y^* y^I}^* > 0$, and $A_3 \equiv R_{y^* y^*}^* R_{y^I y^I}^I - R_{y^* y^I}^* R_{y^I y^*}^I > 0$. Thus each firm's output reaction curve is downward sloping because outputs are substitutes. However, effects of R&D activities on output levels depend on northern and southern countries' IP protection enforcement levels. Assuming $c_x = c_x^* = c_x^I$ and totally differentiating the first-order conditions with respect to y , y^* , and x , we obtain the following comparative static matrix equation:

$$(39) \quad \begin{bmatrix} R_{yy} & R_{yy^*} & R_{yy'} \\ R_{y^*y} & R_{y^*y^*} & R_{y^*y'} \\ R_{y'y} & R_{y'y^*} & R_{y'y'} \end{bmatrix} \begin{bmatrix} y_x \\ y_x^* \\ y_x' \end{bmatrix} = \begin{bmatrix} c_x \\ \theta^* c_x^* \\ \theta' c_x' \end{bmatrix}.$$

Using (39), we show the effects of R&D investment on output levels as follows:

$$(40) \quad \begin{aligned} y_x &= \frac{c_x}{B} \left[A_3 + \theta^* (R_{yy'} R_{y'y'}^* - R_{yy} R_{y'y'}) + \theta' (R_{yy^*} R_{y^*y'} - R_{yy'} R_{y^*y^*}) \right]; \\ y_x^* &= \frac{c_x^*}{B} \left[(R_{y^*y'} R_{y'y}^* - R_{y^*y} R_{y'y'}^*) + A_2 \theta^* + \theta' (R_{yy'} R_{y^*y} - R_{yy} R_{y^*y'}) \right]; \\ y_x' &= \frac{c_x'}{B} \left[(R_{y^*y} R_{y'y}^* - R_{y^*y^*} R_{y'y}^*) + \theta^* (R_{yy^*} R_{y'y}^* - R_{yy} R_{y'y}^*) + \theta' A_1 \right]; \\ y_x^* &= \frac{c_x^*}{B} \left[(R_{yy'} R_{y'y'}^* - R_{yy} R_{y'y'}^*) + A_3 \theta + \theta' (R_{yy^*} R_{y^*y'} - R_{yy'} R_{y^*y^*}) \right]; \\ y_x^* &= \frac{c_x^*}{B} \left[A_2 + \theta (R_{y^*y'} R_{y'y}^* - R_{y^*y} R_{y'y'}^*) + \theta' (R_{yy'} R_{y^*y} - R_{yy} R_{y^*y'}) \right]; \\ y_x' &= \frac{c_x'}{B} \left[(R_{yy^*} R_{y'y}^* - R_{yy} R_{y'y}^*) + \theta (R_{y^*y} R_{y'y}^* - R_{y^*y^*} R_{y'y}^*) + \theta' A_1 \right], \end{aligned}$$

$$B \equiv R_{yy} R_{y^*y}^* R_{y'y'}^* + R_{yy^*} R_{y^*y'} R_{y'y}^* + R_{yy'} R_{y^*y}^* R_{y'y}^*$$

where $-R_{yy'} R_{y^*y}^* R_{y'y}^* - R_{yy^*} R_{y^*y'} R_{y'y}^* - R_{yy} R_{y^*y}^* R_{y'y}^* < 0$ as a stability condition. Those effects of R&D activities on output levels depend on northern and southern countries' IP protection enforcement levels.

We now analyze the R&D stage, in which northern firms choose R&D levels maximizing their own profits. Unlike the previous case, the Nash equilibrium R&D levels are a function of the southern country's IP protection enforcement level as well as strategic trade

policy instruments of northern countries:

$$(41) \quad x = z(s, s^*, e, e^*, \theta, \theta^*, \theta^l); \quad x^* = z^*(s, s^*, e, e^*, \theta, \theta^*, \theta^l).$$

Now we are ready to analyze the policy stage in the North-South setup. Northern countries simultaneously choose their strategic policy instruments: R&D and export subsidies and IPR policy, but only IP protection enforcement for the southern country. We also assume that each government maximizes its domestic welfare as follows:

(P5)

$$\text{Home: } \max_{s, s^*, \theta} W(s, s^*, e, e^*, \theta, \theta^*, \theta^l) \equiv G(z, z^*, \theta, \theta^*, \theta^l, s, e) - sz - eq(z, z^*, e, e^*, \theta, \theta^*, \theta^l)$$

$$\text{Foreign: } \max_{s^*, e^*, \theta^*} W^*(s, s^*, e, e^*, \theta, \theta^*, \theta^l) \equiv G^*(z, z^*, \theta, \theta^*, \theta^l, s^*, e^*) - s^* z^* - e^* q^*(z, z^*, e, e^*, \theta, \theta^*, \theta^l)$$

$$\text{South: } \max_{\theta^l} W^l(s, s^*, e, e^*, \theta, \theta^*, \theta^l) \equiv G^l(z, z^*, \theta, \theta^*, \theta^l) + CS(s, s^*, e, e^*, \theta, \theta^*, \theta^l).^{12}$$

The first-order conditions for northern countries have the same functional forms with (27), (28), and (29). However, the southern country must consider the consumer surplus because it is the only place to consume. See Appendix E for the first-order condition of the southern country's optimization problem. Solving these three equations for policy tools, we can show the following Nash equilibrium in the North-South setup.

Nash Equilibrium in the North-South Setup:¹³⁾

12) The point that we talked about in footnote 2 applies, too.

13) See Appendix E for calculation.

$$\frac{1+\theta^l}{3} < \theta < 1; \quad \theta^l = 1; \quad s = \frac{G_z \cdot \frac{dx^*}{dx} \left(q_z \cdot \frac{dy^*}{dy} q_z \right) - q_z \cdot \left(R_{q^*} \frac{dy^*}{dx} + R_{q^l} \frac{dy^l}{dx} \right)}{q_z \cdot \frac{dy^*}{dy} \frac{dx^*}{dx} + q_z} > 0;$$

$$e = \frac{G_z \cdot \frac{dx^*}{dx} \frac{dy^*}{dy} + q_z \cdot \left(R_{q^*} \frac{dy^*}{dy} + R_{q^l} \frac{dy^l}{dy} \right)}{q_z \cdot \frac{dy^*}{dy} \frac{dx^*}{dx} + q_z} < 0.$$

This verifies that the northern and southern countries set different IPR policy. At the Nash equilibrium, the southern country has no incentive to protect the northern firms' R&D outcome. Thus the southern country has a strong incentive to free ride on the northern R&D outcome. The northern countries' IPR protection enforcement levels are stronger than the southern country's, even though they still have an incentive to free ride on the rival northern firm's R&D outcome. Northern countries need to subsidize their domestic R&D activities because weak IPR protection enforcement damages inventive firms' incentive to invest in R&D activities. In contrast with the Nash equilibrium in Section 3, the northern countries will subsidize their exports because of the existence of an imitator in the southern country. We now summarize our findings for the North-South setup:

Proposition 5 North-South Setup

The southern country will provide no protection for the northern inventive firms' R&D outcome. The northern countries' IPR policy is stronger than that of the southern country. Each northern country needs to subsidize R&D activities in order to boost the R&D investment incentives damaged due to weak IP protection. It also has an incentive to subsidize its exports.

V. Conclusion

This paper has explored how patent infringement affects a strategic trade policy mix: R&D and export subsidies. By endogenizing the decision process of IPR policy, we showed that an exporting country has an incentive to free ride on a foreign rival country's R&D outcome by loosely enforcing IPR protection. The free rider problem stems from public-good nature of R&D activities. Once an idea or process has been developed, the marginal cost of disseminating knowledge is zero. However, weak IP protection would damage inventive firms' incentive to invest in R&D activities. To enhance the damaged incentives for innovation and R&D investment, each exporting country needs to subsidize its domestic R&D activities. In contrast with results of Spencer and Brander (1983), it is shown that the R&D game exhibits positive externalities and that home and foreign R&D activities are strategic complements.

The main contribution of this paper is that the case of strategic R&D subsidies is more robust than previously thought. An exporting country has an incentive to subsidize R&D activities, no matter whether or not exporting countries cooperate to set strategic trade policy. In other words, the optimal R&D subsidy rate is positive, once their equilibrium choices of IPR protection are considered as well. When we consider export subsidies as well as IPR and R&D policies, the robustness of R&D subsidies still holds. In the original SB setup, the addition of export policies leads governments to impose a tax on R&D activities and offer export subsidies, pointing to another way in which the case for strategic R&D subsidies appears to be fragile. However, we showed that this fragility disappears in a setting in which

the choice of IPR protection is modeled as well.

Interestingly, this paper identifies a puzzle as to why governments might wish to agree to provide no protection on IPRs. The implication of this part is not compatible with the fact that the WTO seeks strong enforcement on IPR protection through the TRIPS Agreement. It is important to understand this puzzle because at an international level IPR protection has been a major focus of negotiations along with R&D subsidies. After 7 years of discussion during the Uruguay Round, the WTO prohibited export subsidies but allowed R&D subsidies. However, even though R&D subsidies are allowed the WTO sets an upper bounds: Under the WTO rules, governments may pay up to 75% of the costs of industrial research, or 50% of the costs of pre-competitive development activities. The challenge of the puzzle would be to explain why governments seek to eliminate export subsidies, to allow R&D subsidies but to negotiate limits of their use, and to negotiate strengthening of IPR protection. We leave these and other topics for future research.

Appendix A: Nash Equilibrium with 2 Instruments: R&D Subsidies and IPR Policy

By totally differentiating $G_{z^*} = 0$ with respect to x , x^* , and θ , we can show:

$$(A1) \quad \frac{G_{z^*z}}{G_{z^*z^*}} z_\theta + z_\theta^* + \frac{G_{z^*\theta}}{G_{z^*z^*}} = 0 \rightarrow z_\theta^* - \frac{dx^*}{dx} z_\theta = -\frac{G_{z^*\theta}}{G_{z^*z^*}}$$

Plugging (A1) into (19), we obtain:

$$(A2) \quad -\frac{G_{z^*\theta}}{G_{z^*z^*}} G_{z^*} + R_{q^*} q_\theta^* - q c_\theta = 0.$$

By differentiating $G_{z^*} = 0$ with respect to θ , we obtain

$$(A3) \quad G_{z^*\theta} = (R_{qq} q_\theta + R_{qq^*} q_\theta^*) q_{z^*} + R_{q^*} q_{z^*\theta} - q_\theta^* c_{z^*},$$

where $q_{z^*\theta} = c_{z^*}^* R_{q^*} q^* / A$ from (8). Using (10) and rearranging (A3), we can show

$$(A4) \quad G_{z^*\theta} = q_\theta^* c_{z^*} \left[\theta (R_{qq}^* R_{qq} - (R_{qq^*})^2) - R_{qq^*} (R_{qq}^* - R_{qq}) \right] < 0.$$

Using (2), (10) and (A4), we conclude $G_{z^*} > 0$ from (A2). It implies:

$$(A5) \quad G_{z^*} = R_{q^*} q_{z^*}^* - \theta q c_{z^*} = \frac{c_{z^*}^*}{A} \left[(R_{qq} - \theta R_{q^*q}) R_{q^*} - \theta q A \right] > 0.$$

Using (3), we can conclude that G_{z^*} is positive if $\frac{R_{yy} R_{y^*y^*}}{R_{y^*y} R_{yy^*} + yA} < \theta < 1$. Also, we must check corner solutions. When $G_{z^*} < 0$, (A2) is positive implying that $W_\theta > 0$ and $\theta = 1$. However, this solution is not

compatible with $G_{z^*} < 0$ because if $\theta = 1$, then $G_{z^*} > 0$. For the other corner solution: $\theta = 0$, G_{z^*} is positive and big enough to have $W_\theta < 0$. However, since $\theta = 0$ implies $G_{z^*} < 0$, this corner solution has a contradiction, too.

Appendix B: Joint Optimum with 2 Instruments: R&D Subsidies and IPR Policy

From (20) and the first-order condition of the foreign optimization problem analogous to (20), we can show:

$$(B1) \quad s = G_z^* \quad s^* = G_z^*$$

Plugging these into (21), we rewrite (21) as follows:

$$(B2) \quad R_q q_\theta^* - qc_\theta + R_q q_\theta > 0.$$

It implies $W_\theta > 0$ and hence we need to select $\theta = 1$ so that the joint welfare is maximized.

Appendix C: Nash Equilibrium with 3 Instruments: R&D and Export Subsidies and IPR Policy

Plugging (30) into (28) and using $G_e = R_q q_e + R_{q^*} q_e^* - q_e c + q + e q_e = R_{q^*} q_e^* + q$, we obtain:

$$(C1) \quad G_{z^*} \left(z_e^* - \frac{dx^*}{dx} z_e \right) + R_{q^*} q_e^* - e q_{z^*} \left(z_e^* - \frac{dx^*}{dx} z_e \right) - e q_e = 0.$$

By totally differentiating $G_{z^*} = 0$ with respect to x , x^* , and e , we can show:

$$(C2) \quad \frac{G_{z^*z}^*}{G_{z^*z^*}^*} z_e + z_e^* + \frac{G_{z^*e}^*}{G_{z^*z^*}^*} = 0 \rightarrow z_e^* - \frac{dx^*}{dx} z_e = - \frac{G_{z^*e}^*}{G_{z^*z^*}^*}.$$

Assuming $R_{qq}^* = 0$, we obtain $G_{z^*e}^* = q_e^* (R_{qq^*} q_{z^*}^* - c_{x^*}^*)$ and $G_{z^*z}^* = q_z^* (R_{qq^*} q_{z^*}^* - c_{x^*}^*)$. These equations imply

$$(C3) \quad z_e^* - \frac{dx^*}{dx} z_e = - \frac{G_{z^*e}^*}{G_{z^*z^*}^*} = \frac{q_e^*}{q_z^*} \frac{dx^*}{dx}.$$

Plugging (C3) into (C1), using $q_e^* = q_e \frac{dy^*}{dy}$ from (25) and rearranging (C1), we can show the optimal export subsidies:

$$(C4) \quad e = \frac{\frac{dy^*}{dy} \left(G_{z^*} \frac{dx^*}{dx} + R_{q^*} q_z^* \right)}{q_z^* \frac{dy^*}{dy} \frac{dx^*}{dx} + q_z^*}.$$

Plugging (C4) into (30), we can find the optimal R&D subsidies:

$$(C5) \quad s = \frac{G_z \cdot \frac{dx^*}{dx} \left(q_z - \frac{dy^*}{dy} q_z \right) - R_q q_z \frac{dy^*}{dy} \frac{dx^*}{dx}}{q_z \frac{dy^*}{dy} \frac{dx^*}{dx} + q_z}$$

For the optimal IP protection enforcement level, we need to plug the optimal R&D and export subsidies into (29). Rearranging the equation, we obtain:

$$(C6) \quad \left(G_z - R_q q_z \frac{dy^*}{dy} \right) \left[q_z \left(z_\theta - \frac{dx^*}{dx} z_\theta \right) - q_\theta \frac{dy^*}{dy} \frac{dx^*}{dx} \right] - q c_\theta \left(q_z \frac{dy^*}{dy} \frac{dx^*}{dx} + q_z \right) = 0.$$

For simplicity, we assume that the demand for the final good is linear:

$$\text{Since } G_z - R_q q_z \frac{dy^*}{dy} = \frac{q c_z}{2} (1 - 2\theta), \quad q_z \left(z_\theta - \frac{dx^*}{dx} z_\theta \right) - q_\theta \frac{dy^*}{dy} \frac{dx^*}{dx} = \frac{-2}{9 G_{zz}} q^* c_z c_z (1 - 2\theta),$$

and $q_x^* = \frac{c_x^* (1 - 2\theta)}{3}$, we can show the optimal IP protection enforcement level should be greater than $\frac{1}{2}$, which is R_{qq^*} / R_{qq} . Furthermore, we can show that the optimal R&D subsidy rate is positive and that the export subsidy rate is negative at the Nash IP protection enforcement level.

Appendix D: Joint Optimum with 3 Instruments: R&D and Export Subsidies and IPR Policy

From (31) and the first-order condition of the foreign optimization problem analogous to (31), we can find the optimal R&D subsidies as follows:

$$(D1) \quad s = G_z - eq_z - e^* q_z^*; \quad s^* = G_{z^*} - eq_{z^*} - e^* q_{z^*}^*.$$

Plugging these into (32) and rearranging, we obtain the optimal export subsidies:

$$(D2) \quad e = R_q^* < 0; \quad e^* = R_{q^*} < 0.$$

Then the jointly optimal R&D subsidies are given: $s = G_z - R_q^* q_z^* = R_q^* q_z^*$. Since $G_z^* = R_q^* q_z^* - \theta^* q^* c_z^*$, we can show the following jointly optimal R&D subsidies:

$$(D3) \quad s = -R_q^* q_z^* - \theta^* q^* c_z^*; \quad s^* = -R_{q^*} q_{z^*}^* - \theta q c_{z^*}^*.$$

For the jointly optimal IP protection enforcement level, we need to plug (D1) and (D2) into (33). Then we obtain the following result:

$$(D4) \quad W_\theta + W_\theta^* = -qc_\theta - R_q^* q_\theta - R_{q^*} q_\theta^* > 0.$$

Therefore, we need to select $\theta = 1$ so that the joint welfare is maximized.

Appendix E: Nash Equilibrium in the North-South Setup

The first-order conditions are given as follows:

$$(E1) \quad G_z z_s + G_z z_s^* + G_s - z - sz_s - e(q_z z_s + q_z z_s^*) = 0;$$

$$(E2) \quad G_z z_e + G_z z_e^* + G_e - sz_e - q - e(q_z z_e + q_z z_e^* + q_e) = 0;$$

$$(E3) \quad G_z z_\theta + G_z z_\theta^* + G_\theta - sz_\theta - e(q_z z_\theta + q_z z_\theta^* + q_\theta) = 0.$$

Since $G_z = 0$, $G_s = z$ and $z_s^*/z_s = dx^*/dx$ from (15), one can show that the optimal R&D subsidy rate is given:

$$(E4) \quad s = G_z \cdot \frac{dx^*}{dx} - e \left(q_z + q_z \cdot \frac{dx^*}{dx} \right).$$

Plugging (E4) into (E2) and using $G_e = R_q q_e^* + R_q q_e^I + q$, we obtain:

$$(E5) \quad G_z \cdot \left(z_e^* - \frac{dx^*}{dx} z_e \right) + R_q q_e^* + R_q q_e^I - e q_z \cdot \left(z_e^* - \frac{dx^*}{dx} z_e \right) - e q_e = 0.$$

Prior to rearrange (E5), we need to find the effects of export subsidies on output levels. Totally differentiating the first-order conditions with respect to y , y^* , and θ , we obtain the following comparative static matrix equation as follows:

$$(E6) \quad \begin{bmatrix} R_{yy} & R_{yy^*} & R_{yy'} \\ R_{y^*y} & R_{y^*y^*} & R_{y^*y'} \\ R_{y'y} & R_{y'y^*} & R_{y'y'} \end{bmatrix} \begin{bmatrix} y_e \\ y_e^* \\ y_e' \end{bmatrix} = \begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix}.$$

Using (E6), we show the effects of IPR policy on output levels:

$$(E7) \quad y_e = -\frac{A_3}{B} > 0; \quad y_e^* = -\frac{R_{y^*y'}^* R_{y'y}^I - R_{y^*y}^* R_{y'y'}^I}{B} < 0;$$

$$y_e^I = -\frac{R_{y^*y}^* R_{y'y'}^I - R_{y^*y'}^* R_{y'y}^I}{B} < 0.$$

Using (C3) from Appendix C, $q_e^* = q_e \frac{dy^*}{dy}$ and $q_e^I = q_e \frac{dy^I}{dy}$ from (E7), and rearranging (E5), we can show the optimal export and R&D subsidies:

$$(E8) \quad s = \frac{G_z \frac{dx^*}{dx} \left(q_z^* - \frac{dy^*}{dy} q_z \right) - q_z^* \left(R_{q^*} \frac{dy^*}{dx} + R_{q^I} \frac{dy^I}{dx} \right)}{q_z^* \frac{dy^*}{dy} \frac{dx^*}{dx} + q_z^*} > 0;$$

$$(E9) \quad e = \frac{G_z \frac{dx^*}{dx} \frac{dy^*}{dy} + q_z^* \left(R_{q^*} \frac{dy^*}{dy} + R_{q^I} \frac{dy^I}{dy} \right)}{q_z^* \frac{dy^*}{dy} \frac{dx^*}{dx} + q_z^*} > 0.$$

For the optimal IP protection enforcement level, we need to plug the optimal R&D and export subsidies into (E3). For simplicity, we assume that the demand for the final good is linear. Prior to rearrange (E3), we need to find the effects of IP protection enforcement on output. Totally differentiating the first-order conditions with respect to y , y^* , and θ , we obtain the following comparative static matrix equation as follows:

$$(E10) \begin{bmatrix} R_{yy} & R_{yy^*} & R_{yy^I} \\ R_{y^*y} & R_{y^*y^*} & R_{y^*y^I} \\ R_{y^Iy} & R_{y^Iy^*} & R_{y^Iy^I} \end{bmatrix} \begin{bmatrix} y_{\theta} \\ y_{\theta}^* \\ y_{\theta}^I \end{bmatrix} = \begin{bmatrix} c_{\theta} \\ 0 \\ 0 \end{bmatrix}.$$

Using this, we show the effects of IPR policy on output levels as follows:

$$(E11) \quad y_{\theta} = c_{\theta} \frac{A_3}{B} > 0; \quad y_{\theta}^* = c_{\theta} \frac{R_{y^*y^I} R_{y^Iy} - R_{y^*y} R_{y^Iy^I}}{B} < 0;$$

$$y_{\theta}^I = c_{\theta} \frac{R_{y^*y} R_{y^Iy^*} - R_{y^*y^*} R_{y^Iy}}{B} < 0.$$

Then we can rewrite (E3) as follows assuming the linear demand:

$$(E12) \quad qc_z(3\theta - \theta^I - 1) \left(z_{\theta}^* - \frac{dx^*}{dx} z_{\theta} \right) + 3qc_{\theta} = 0.$$

For (E12), we can conclude that $\frac{1+\theta^I}{3} < \theta < 1$.

For the southern country's optimization problem, the first-order condition is given as follows:

$$(E13) \quad G_z^I z_{\theta^I} + G_z^I z_{\theta^I}^* + G_{\theta^I}^I + CS_{\theta^I} = 0.$$

The derivative of the consumer surplus with respect to the southern IP protection enforcement level is defined as follows:

$$(E14) \quad CS_{\theta'} = -(q + q^* + q') \left[\frac{dp}{dy} (q_z z_{\theta'} + q_{z^*} z_{\theta'}^* + q_{\theta'}') + \frac{dp}{dy^*} (q_z^* z_{\theta'}^* + q_{z^*}^* z_{\theta'}^{*'} + q_{\theta'}^{*'}) \right] + \frac{dp}{dy'} (q_z^l z_{\theta'}^l + q_{z^*}^l z_{\theta'}^{l'} + q_{\theta'}^{l'})$$

It turns out that every component of (E13) is positive, implying that $W_{\theta'}^d > 0$. Thus the optimal southern IP protection enforcement level is 1. In other words, the southern country has no incentive to protect the northern R&D outcome at all.

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國文要約

전략적 무역정책으로서의 R&D 보조금이 기업의 R&D 투자결정에 영향을 미칠 수 있다는 것은 기존의 연구에서 잘 알려진 사실이다. 본 논문에서는 각국의 지적 재산권 보호수준 역시 기업의 R&D 투자결정에 영향을 미칠 수 있는 정책 변수임에 착안하여 각국의 지적 재산권 정책을 내생화함에 의하여 기존의 논의를 발전시킨다. 따라서, 각국의 정부는 지적 재산권 보호수준 및 R&D 보조금 정책을 동시에 병행할 수 있다. 이 경우 정부는 외국 경쟁기업에 대한 지적재산권 보호를 느슨하게 하고 자국 기업에 대해서는 R&D 보조금을 지불하는 것이 Nash균형이다. 또한, 이 논문은 기존의 연구결과와는 달리 R&D 보조금의 이론적 기반이 더욱 확대됨을 증명한다. 각 수출국가는 수출국가간 협력의 유무에 상관없이 자국의 기업에게 R&D 보조금을 지급할 유인을 가진다. 기존의 연구에서는 수출국가간 정책 협조가 이루어질 경우 과도한 R&D 투자경쟁을 없애기 위하여 R&D 투자에 세금을 부과하는 것이 최선의 정책이었으나, 지적재산권 보호 문제를 동시에 고려할 경우 R&D 투자로 습득된 지식을 공유하게 유도하고 이러한 지적재산권의 불완전한 보호가 미치는 투자유인의 저하를 R&D 보조금으로 해결하는 것이 최선의 정책 협조인 것으로 나타났다.

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