R&D Subsidy, Intellectual Property Rights Protection, and North-South Trade

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Abstract

This paper investigates the competition in technology and production between a firm in the North (developed country) and a firm in the South (developing country), and how such competition may be affected by North's subsidy on technology improvement and South's intellectural property rights (IPR) protection level. It is argued that allowing the North to choose the policy first could bring Pareto improvement. The paper also shows why requiring only the South to tighten its IPR protection without putting similar pressure on the North (the TRIPs case) hurts the South. A more rewarding outcome exists if both the IPR protection level and the subsidy rate are chosen optimally.

1 Introduction

The rapid growth in intellectual property trade and the growing importance of high-technology products in world trade have made intellectual property rights (IPR) protection an important issue in the last two decades. Advanced industrialized countries, the United States in particular, wanted to increase international protection of intellectual property to prevent developing countries from pirating, counterfeiting, and imitating knowledge created by companies in those industrialized countries. In the Uruguay Round of the General Agreement on Tariffs and Trade (GATT), the so-called new issue of trade-related aspects of intellectual property rights (TRIPs) was added to the agenda and the Agreement on TRIPs was reached, even though it was strongly resisted by developing countries. Most of the terms of the TRIPs Agreement required that developing countries adopt the same IPR standards as the prevailing ones in developed countries at the time of the negotiation. Developing countries regarded the Agreement as an attempt by developed countries to exploit monopoly power and extract economic rents at the expense of developing countries. Given that the TRIPs Agreement benefits developed countries at the expense of developing countries, a quid pro quo provided by the former is necessary to make the Agreement more sustainable. For example, lowering trade barriers against goods coming from developing countries was the most common concession offered by developed countries to developing countries in the IPR negotiation. Thus, the issue of IPR protection and its close link with trade policies have been getting more consideration in multilateral trade negotiations. Anticipating these negotiations, there have been theoretical studies on the welfare effects of strengthening IPR protection, for example, Chin and Grossman (1990), Diwan and Rodrik (1991), Deardorff (1992), Helpman (1993) and Zigic (1998). However, studies on the interaction between IPR protection policy and trade policies are scarce. Both Zigic (2000) and Qiu and Lai (2001) investigate the interaction between IPR protection and tariffs under the North (developed countries) and South (developing countries) trade model. Zigic (2000) finds that imposing tariffs can be a strategic policy instrument used by the Northern government to countervail loose Southern IPR protection. Qiu and Lai (2001) focus on the different roles of Northern and Southern tariffs when IPR protections in both regions are weak.

Competition policies, other than tariffs and other non-tariff protection policies, that can be used as quid pro quo are gaining more attention from policy makers in developed countries. For example, industrial policies, such as production or R&D subsidies/taxes, have been used as strategic instruments, undertaken by governments in an attempt to affect the competitiveness of their firms and the welfare of their consumers in oligopolistic industries. In the three-stage game of industrial strategy pioneered by Spencer and Brander (1983), an R&D subsidy, like an export subsidy, plays a profit-shifting role and it allows the firm to achieve the outcome that would obtain if it were able to act as a Stackelberg leader with respect to its rival. The justification for such an R&D policy is evident because the two competing firms engage in R&D competition and an R&D subsidy enhances the firm's incentive to overinvest in R&D. Even when the firms engage in R&D cooperation, Qiu and Tao (1998) show that an R&D tax is never optimal with linear demands in the case of R&D collaboration, and an R&D subsidy is always optimal in the case of R&D coordination. However, in the North-South IPR protection model, the main issue is that innovative R&D or technological knowledge created by North are imitated by the South because of loose Southern IPR protection. Whether there still exists the rationale for an R&D subsidy by the Northern government is unclear.

The purpose of this paper is to investigate the competition in technology and production between two firms, one in the North (developed country) and one in the South (developing country), and how such competition may be affected by North's subsidy on technology improvement and South's intellectual property rights (IPR) protection level. Both governments choose appropriate policies to affect the firms' competition, trying to find a balance between its own firm's profit and its consumers' utility in order to maximize its society's welfare. In such a model, governments have to care about how the firms compete and react to the policies, and how its national welfare may be affected by the other country's policy.

The main issue in this paper is how the South chooses its optimal IPR protection level, and how this level may be dependent on the policy of the North and the R&D that the North firm may choose. Obviously South's policy choice depends on the how the governments choose their policy parameters. Two different games are considered. In the first one, both governments choose their policies simultaneously, and then the firms choose their R&D (by the one in the North) and production. In the second one, government in the North chooses the R&D subsidy rate first and then the South chooses the IPR protection. As compared with the first case, the North wants to induce the South to tighten the IPR protection, but whether it should provide more subsidy to bribe the South (the Bribing-with-a-Carrot case) or to whip the South and force it to provide more IPR protection (the Whipping-with-a-Stick case) depends on how the South reacts. However, we show that in the Bribing-with-a-Carrot case, letting the North to take the first move could provide a Pareto improvement.

This paper also examines the choice of IPR protection level to maximize the world welfare. This is close to the TRIPs agreement, which requires all countries to provide the same or similar IPR protection. Since developed countries usually have already had very tight IPR protection, the agreement works mostly against the developing countries. This paper argues that this agreement hurts the South for two possible reasons: The South is forced to tighten its IPR protection, and the North provides less subsidy, giving the South the second blow. As a matter, an alternative approach is suggested in this paper. To maximize world welfare, not only should the IPR protection is chosen, but also should the subsidy rate offered to the firm in the North.

The remainder of the paper is organized as follows: Section 2 provides the features and assumptions of the model. Section 3 a game in which both governments choose their policy parameters simultaneously. The optimal production levels and the optimal R&D activities are derived. In section 4, the optimal subsidy rate and the optimal IPR protection are derived. The Whipping-with-a-Stick case and the Bribing-with-a-Carrot case are explained. Section 5 examines the case in which the North is able to choose a credible subsidy first before the South picks its IPR protection. Section 6 considers the IPR that maximize the world welfare. Two cases are explained: the one in which the North chooses its own subsidy rate, and the one in which both the IPR protection level and the subsidy rate are chosen to maximize the world welfare. The last section concludes.

2 The Model

Consider two countries labeled North and South and a homogeneous product. In each country, there is one firm producing the product. The firm in North (South) is named firm N (S). The demand for the product, x_i, in country i is represented by $p^i = p^i(x^i)$, $i = n, s$, where the subindex n (s) is used to denote a variable of North (South), and p^i is the market price. The demand function satisfies the normal properties: $p^{i\prime}(x^i) < 0$ and $p^{i\prime\prime}(x^i) < \varsigma$, where ς is a sufficiently small positive number and a prime represents a derivative.

Under free trade and zero transport costs, the markets are assumed to be fully integrated so that in equilibrium the two countries face the same market price of the product. The two demand functions can be combined together to give an aggregate demand function, $p = p(X)$.[1]

Initially firm N is able to produce the product with a marginal cost of α^n while firm S's initial marginal cost is α^s, where $\alpha^s > \alpha^n$, showing the case in which initially firm N has a superior technology. Both marginal costs are independent of the production level, and for simplicity both firms' fixed costs are insignificant. Both firms are able to improve its technology, i.e., to lower their marginal costs, through different channels. Firm N can invest in R&D. For example, by spending an amount of k on R&D, it is able to lower its marginal cost by an amount of $f(k)$, where $f'(k) > 0$ and $f''(k) < 0$, with $f'(0)$ sufficiently big and $f'(\infty) \to 0$. Firm S either is not able to carry out any R&D activities or chooses not to. It improves its technology through spillover effects, but the extent of the spillover depends on how tight South's government protects intellectual property rights (IPR).[2] Let us use a variable $\beta \in [0, 1]$ to represent the degree of IPR. Specifically, given that firm N has spent k on R&D, firm S can expect to lower its marginal cost by $\beta f(k)$ through spillover. This also means that a lower β represents a tighter control of IPR. Through R&D and spillover, the marginal costs of firms N and S are given by, respectively,

$$c^n = \alpha^n - f(k) \tag{1a}$$
$$c^s = \alpha^s - \beta f(k). \tag{1b}$$

Both marginal costs depend on firm N's R&D, but firm S's marginal cost is also affected by the degree of IPR protection chosen by South. For meaningful analysis, we assume that firm N's R&D is not so significant that the resulting marginal cost c^n is positive. The firms use the marginal costs given by conditions (1), and compete in a Cournot fashion.

Both governments have incentives in the present setup to intervene in the markets. In the present paper, we consider only policies toward technology improvement but not trade policies, so that trade remains free between the countries. In North, there is a positive externality in R&D because the firm

[1]It can be shown that $p'(X) < 0$ and $p''(X)$ is less than a sufficiently small, positive number.

[2]Both firm N and North's government also have an incentive to protect the firm's intellectual property rights.

ignores the benefit for the consumers. So the government is willing to provide certain subsidy to the firm to encourage more R&D. For the government in South, IPR protection generates two opposing forces. First, it reduces the spillover effect and its firm gets a small technological improvement. On the other hand, firm N will be encouraged by such protection and thus is willing to invest more in R&D, indirectly benefiting firm S and the consumers. As a result, South's government may want to choose certain degree of IPR protection.

3 Simultaneous Policies

We now analyze the optimal policies of the governments. In this section, we assume that the governments choose their policies simultaneously. Specifically, we consider a three-stage game. In stage 1, the North government chooses an R&D subsidy with a specific rate of $s < 1$, and the South government chooses β, the degree of IPR protection. In stage 2, firm N chooses the level of R&D, k, and spillover occurs. In stage 3, both firms compete in a Cournot sense.

We first consider stage 3. Denote the output of firm i by q^i, $i = n, s$. In equilibrium, the total supply is equal to the total demand:

$$Q \equiv q^n + q^s = x^n + x^s. \tag{2}$$

Firms N and S, respectively, choose an output level to maximize their own profit,

$$\pi^n = p(q^n + q^s)q^n - c^n q^n - (1 - s)k \tag{3a}$$
$$\pi^s = p(q^n + q^s)q^s - c^s q^s, \tag{3b}$$

taking the specific subsidy rate $s < 1$, each other's output, and the marginal costs as given. In condition (3a), $(1 - s)k$ is the net expenditure on R&D by firm N. The first-order conditions of the firms' problems are

$$p'q^n + p = c^n \tag{4a}$$
$$p'q^s + p = c^s. \tag{4b}$$

Conditions (4) yield two reaction functions of the firms, which are solved for the Nash equilibrium outputs as functions of k and β, $\tilde{q}^n(k, \beta)$ and $\tilde{q}^s(k, \beta)$.

Note that the Nash equilibrium outputs depend on the firms' marginal costs, and thus on k and β, but not on s, which in this stage is treated as if it is part of the fixed cost. Differentiate conditions (4) and rearrange the terms to give

$$\begin{bmatrix} p''\tilde{q}^n + 2p' & p''\tilde{q}^n + p' \\ p''\tilde{q}^s + p' & p''\tilde{q}^s + 2p' \end{bmatrix} \begin{bmatrix} \mathrm{d}\tilde{q}^n \\ \mathrm{d}\tilde{q}^s \end{bmatrix} = - \begin{bmatrix} f' \\ \beta f' \end{bmatrix} \mathrm{d}k - \begin{bmatrix} 0 \\ f(k) \end{bmatrix} \mathrm{d}\beta. \tag{5}$$

Condition (5) is then solved for the effects of k and β on the outputs:

$$\frac{\partial \tilde{q}^n}{\partial k} = \frac{p'f'(\beta - 2) + f'p''(\beta \tilde{q}_n - \tilde{q}_s)}{\tilde{D}} > 0 \tag{6a}$$

$$\frac{\partial \tilde{q}^s}{\partial k} = -\frac{p'f'(2\beta - 1) + f'p''(\beta \tilde{q}^n - \tilde{q}^s)}{\tilde{D}} \tag{6b}$$

$$\frac{\partial \tilde{Q}}{\partial k} = -\frac{f'p'(1+\beta)}{\tilde{D}} > 0 \tag{6c}$$

$$\frac{\partial \tilde{q}^n}{\partial \beta} = \frac{f(p''\tilde{q}^n + p')}{\tilde{D}} < 0 \tag{6d}$$

$$\frac{\partial \tilde{q}^s}{\partial \beta} = -\frac{f(p''\tilde{q}^n + 2p')}{\tilde{D}} > 0 \tag{6e}$$

$$\frac{\partial \tilde{Q}}{\partial \beta} = -\frac{fp'}{\tilde{D}} > 0. \tag{6f}$$

where $\tilde{D} \equiv p'p''(\tilde{q}^n + \tilde{q}^s) + 3p'^2 > 0$. In determining the signs of the derivatives in conditions (6), the assumption that the demand curve is not too convex to the origin has been used. However, even with this assumption, the sign of $\partial \tilde{q}^s / \partial k$ remains ambiguous. There are two effects of an increase in k on the output of firm S: the negative *rivalry* effect caused by an increase in firm N's output and the positive *spillover* effect as firm S learns from firm N. Condition (6b) shows that, when p'' is insignificant (as in the case of a linear demand function), the spillover effect outweighs the rivalry effect if and only if $\beta > 0.5$. Condition (6c) shows that the effect of an increase in k on the total output is always positive. Conditions (6d) to (6f) mean that an increase in β (a reduction in IPR protection) implies a decrease in firm N's output, but an increase in firm S's output and the total output.

Once the outputs of the firms have been determined, the market price and the demand of each country can also be found. Furthermore, the effects of k and β on the price and demands are

$$\frac{\partial \tilde{p}}{\partial k} = \frac{\partial \tilde{p}}{\partial Q}\frac{\partial \tilde{Q}}{\partial k} = -\frac{f' p'^2 (1+\beta)}{\tilde{D}} < 0 \tag{7a}$$

$$\frac{\partial \tilde{x}^i}{\partial k} = \frac{\partial \tilde{x}^i}{\partial p^i}\frac{\partial \tilde{p}}{\partial k} = -\frac{f' p'^2 (1+\beta)}{p^{i\prime} \tilde{D}} > 0 \tag{7b}$$

$$\frac{\partial \tilde{p}}{\partial \beta} = \frac{\partial \tilde{p}}{\partial Q}\frac{\partial \tilde{Q}}{\partial \beta} = -\frac{f p'^2}{\tilde{D}} < 0 \tag{7c}$$

$$\frac{\partial \tilde{x}^i}{\partial \beta} = \frac{\partial \tilde{x}^i}{\partial p^i}\frac{\partial \tilde{p}}{\partial \beta} = -\frac{f p'^2}{p^{i\prime} \tilde{D}} > 0, \tag{7d}$$

for $i = n, s$. Conditions (7) imply that an increase in either k or β encourages firms' total output, drives down the market price, and encourages both countries' demands. The R&D subsidy s has no direct effect on the market price, outputs, and demands.[3]

We now turn to stage 2 of the game, in which firm N chooses the level of R&D. Its profit function can now be written as

$$\pi^n(k, \beta, s) = p(\tilde{Q})\tilde{q}^n(k, \beta) - [\alpha^n - f(k)]\tilde{q}^n(k, \beta) - (1-s)k. \tag{8}$$

Differentiate $\pi^n(k, s, \beta)$ with respect to k, taking the policy parameters s and β as given, to yield the first-order condition:

$$\pi_k^n \equiv \frac{\partial \pi^n}{\partial k} = -\frac{p'^2 f' \tilde{q}^n (2\beta - 1)}{\tilde{D}} - \frac{f' \tilde{q}^n p' p'' (\beta \tilde{q}^n - \tilde{q}^s)}{\tilde{D}} + f' \tilde{q}^n - (1-s) = 0, \tag{9}$$

where for convenience we use a subscript to represent a partial derivatives. Condition (9) is solved for the optimal level of R&D, $\tilde{k}$, when facing the given policy parameters.

Let us examine some features of this optimal choice. First, note that by using the definition of $\tilde{D}$ the derivative of π^n with respect to k as given by (9) can be rewritten as

$$\pi_k^n = \frac{2p'^2 f' \tilde{q}_n (2-\beta) - \tilde{q}^n f' p' p'' [(\beta - 1)\tilde{q}^n - 2\tilde{q}^s]}{\tilde{D}} - (1-s). \tag{10}$$

[3] A change in the subsidy rate does have indirect effects through a change in the R&D activities.

Since it is assumed that $f'(k)$ is sufficiently large for small values of k, condition (10) implies that small values of k is beneficial. Furthermore, since $f'(\infty) \to 0$, the condition also implies that $\mathrm{d}\pi_n/\mathrm{d}k < 0$, as long as s is not too high. Thus we conclude that the optimal k is positive and finite. Second, define A so that

$$A = \frac{p'^2 f' \tilde{q}_n}{\tilde{D}} + \frac{\tilde{q}^n f' p' p'' \tilde{q}^s}{\tilde{D}} + f'\tilde{q}^n - (1-s).$$

If there is no spillover effect, $\beta = 0$. Then the firm will choose $\breve{k}$ so that $A = 0$. Note that

$$-\frac{2\beta p'^2 f' \tilde{q}_n}{\tilde{D}} - \frac{(\tilde{q}^n)^2 f' p' p'' \beta}{\tilde{D}} < 0.$$

Therefore at $\tilde{k}$, $A > 0$, as condition (9) shows. Thus $\tilde{k} < \breve{k}$, meaning that because of the spillover effect, firm N tends to spend less on R&D.

To get more properties of the R&D choice, we need to differentiate the first-order condition (9), but the derivatives will depend on the third derivative of the demand function. For a simpler analysis and insights into the present issues, we assume from now on that the demand functions of both countries are linear, implying that the integrated demand function is also linear, i.e., $p'' = 0$. Condition (9) reduces to

$$\pi_k^n = \frac{2}{3} f' \tilde{q}^n (2-\beta) - (1-s) = 0. \tag{11}$$

The derivatives of π_k^n are

$$\pi_{kk}^n = \frac{2(2-\beta)[3p'f''\tilde{q}^n - f'^2(2-\beta)]}{9p'} \tag{12a}$$

$$\pi_{ks}^n = 1 > 0 \tag{12b}$$

$$\pi_{k\beta}^n = \frac{2f'[f(2-\beta) - 3\tilde{q}^n p']}{9p'} < 0. \tag{12c}$$

Note that the sign of π_{kk}^n is unknown but for the second-order condition we assume that it is negative in the region close to the equilibrium point.[4]

[4] The second-order condition is satisfied if $f''(k)$ is numerically very large, i.e., $f'(k)$ drops sufficiently rapidly.

Conditions (12) can be used to show the dependence of the optimal k on the policy parameters:

$$\frac{\partial k}{\partial s} = -\frac{\pi^n_{ks}}{\pi^n_{kk}} = -\frac{9p'}{2(2-\beta)[3p'f''\tilde{q}^n - f'^2(2-\beta)]} > 0 \tag{13a}$$

$$\frac{\partial k}{\partial \beta} = -\frac{\pi^n_{k\beta}}{\pi^n_{kk}} = -\frac{f'[f(2-\beta) - 3\tilde{q}^n p']}{(2-\beta)[3p'f''\tilde{q}^n - f'^2(2-\beta)]} < 0. \tag{13b}$$

The above results are summarized by the following proposition:

Proposition 1 *The optimal R&D chosen by firm N increases with a higher R&D subsidy and/or an increase in IPR protection offered by South.*

Note that because the optimal R&D depends on the policy parameters, a reduced-form profit function can be defined as

$$\tilde{\pi}^n(\beta, s) \equiv \pi^n(k(\beta, s), \beta, s).$$

4 Policy Decisions of the Governments

We now turn to the governments and stage 1 of the game, in which the governments choose their policies in a non-cooperative way. We begin with North's government.

4.1 North's Subsidy

The country's welfare can be defined as the sum of the profit of the firm $\tilde{\pi}^n(\beta, s)$, the consumer surplus, Φ^n, less the subsidy expenditure, sk:[5]

$$W^n(\beta, s) = \tilde{\pi}^n(\beta, s) + \int_p^{\bar{p}^n} x^n(v)\mathrm{d}v - sk. \tag{14}$$

In (14), p is the equilibrium price and $\bar{p}^n$ is the critical price above which the demand in North is zero. The second term on the right hand side is the

[5]Because of a linear demand function, $\bar{p}^n$ is finite.

consumer surplus, $\Phi^n(x^n(p(Q(k(\beta,s),\beta))))$. Differentiate equation (14) with respect to s, taking β as given, to give:

$$\begin{aligned}
\frac{\partial W^n}{\partial s} &= \frac{\partial \tilde{\pi}^n}{\partial s} - x^n \frac{\partial p}{\partial Q}\frac{\partial Q}{\partial k}\frac{\partial k}{\partial s} - k - s\frac{\partial k}{\partial s} \\
&= -\left(x^n \frac{\partial p}{\partial Q}\frac{\partial Q}{\partial k} + s\right)\frac{\partial k}{\partial s} \\
&= -\left(-\frac{x^n f'(1+\beta)}{3} + s\right)\frac{\partial k}{\partial s}. \qquad (15)
\end{aligned}$$

Setting the derivative in condition (15) to zero and rearranging the terms gives the optimal subsidy rate, when taking South's IPR protection policy as given. The first-order condition can be written as:[6]

$$s^* = \frac{x^n f'(1+\beta)}{3} > 0, \qquad (16)$$

for $x^n > 0$. Alternatively, express the consumer surplus as $\Phi^n = \tilde{\Phi}^n(k,\beta) \equiv \Phi^n(x^n(p(Q(k(\beta,s),\beta))))$. This gives an alternative expression for the optimal subsidy can be given in terms of the consumer surplus,

$$s^* = \frac{\partial \tilde{\Phi}^n}{\partial k}. \qquad (17)$$

Condition (16) or (17) gives North's reaction function, $s^* = R^n(\beta)$. An interesting implication of (16) is that if there is no domestic consumption in North, the optimal subsidy is zero. It is because national welfare of the country will be defined as the profit of firm N, which the firm will maximize.[7]

The reaction function of North can be shown by curve AB in Figures 1 and 2, which is marked as $R^n(\beta)$. The diagrams also show two iso-welfare contours of North corresponding to two welfare levels, W_1^n and W_2^n, with $W_2^n > W_1^n$. The reaction curve AB is the locus of points on the iso-welfare contours with a slope equal to infinity. To obtain the slope of the reaction curve, differentiate (16) with respect to β to give

$$\left.\frac{\mathrm{d}s^*}{\mathrm{d}\beta}\right|_{\mathrm{AB}} = \frac{f' x^{n\prime} p' \phi(1+\beta)}{3} + \frac{x^n f''(1+\beta)k_\beta}{3} + \frac{x^n f'}{3}, \qquad (18)$$

[6] We note from (13a) that $\partial k/\partial s \neq 0$.

[7] It should be noted that the subsidy considered in the present model does not have the usual profit-shifting effect because in the second stage only firm N acts and in the third stage it does not affect the outputs of the firms directly.

where

$$\phi = \frac{\partial Q}{\partial k}\frac{\partial k}{\partial \beta} + \frac{\partial Q}{\partial \beta}. \tag{19}$$

The variable ϕ measures the total effect of β on the total output of the firms. We assume the general case in which $\phi \geq 0$, a condition which is satisfied when $\partial k/\partial \beta$ is sufficiently small.

Condition C. Either (i) $\phi \geq 0$ or (ii) $\partial^2 \Phi^n/\partial k^2 \leq 0$.

Lemma 1. Given condition C, North's reaction curve is positively sloped.

Proof. Substitute condition C(i) into (18), we get the sign of the reaction curve. Differentiate condition (17) with respect to β to give

$$\left.\frac{\mathrm{d}s^*}{\mathrm{d}\beta}\right|_{\mathrm{AB}} = \frac{\partial^2 \tilde{\Phi}^n}{\partial k^2}\frac{\partial k}{\partial \beta} + \frac{\partial^2 \tilde{\Phi}^n}{\partial k \partial \beta}. \tag{20}$$

Using the definition of function $\tilde{\Phi}^n(k, \beta)$ and previous analysis, it can be shown that

$$\frac{\partial^2 \tilde{\Phi}^n}{\partial k \partial \beta} = \frac{1}{3}\left(x^n f' + f' x^{n\prime} p'(1+\beta)\frac{\partial Q}{\partial \beta}\right) > 0. \tag{21}$$

Since $\partial k/\partial \beta < 0$, conditions C(ii), (20), and (21) imply that North's reaction curve is positively sloped. ■

Condition C is only a necessary but not sufficient condition for a positively sloped curve $R^n(\beta)$.

4.2 South's IPR Protection

Let us now turn to the government of South. Its national welfare can be defined as the sum of firm S's profit $\tilde{\pi}^s$ and the consumer surplus Φ^s :

$$W^s(\beta, s) = \tilde{\pi}^s(\beta, s) + \int_p^{\bar{p}^s} x^s(v)\mathrm{d}v, \tag{22}$$

where $\bar{p}^s$ is the market price above which the demand of South is zero. The problem of the government is to choose $\beta \in [0, 1]$, taking s as given, to maximize $W^s(\beta, s)$. Differentiate the national welfare given in (22) with respect to β, taking s as given, to give:

$$W^s_\beta = p' q^s \sigma + f q^s + \beta f' q^s k_\beta - x^s p' \phi, \tag{23}$$

where

$$\sigma = \frac{\partial q^n}{\partial k}\frac{\partial k}{\partial \beta} + \frac{\partial q^n}{\partial \beta} < 0.$$

The sign of W^s_β is ambiguous. To determine the optimal β subject to s, solve the following condition

$$W^s_\beta = 0. \tag{24}$$

If the solution is unique and lies between zero and one, and if the second-order condition is satisfied, then the solution gives the optimal β. Otherwise, the optimal value of β will be either zero or one. Since the solution is given in terms of a given s, it can be regarded as South's reaction function, $\beta^* = R^s(s)$.

Let us consider the following two special cases:

1. Complete Free-Riding Case. In this case, $\beta^* = 1$ for all possible values of s. In terms of Figure 1 or 2, the reaction curve of South is a vertical line at $\beta = 1$. In this case, South never wants to impose any IPR protection.

2. Complete IPR Protection Case. This is the case in which $\beta^* = 0$ for all possible values of s, i.e., South always has perfect IPR protection, allowing no technology spillover, no matter what North does. The reaction curve of South coincides with the vertical axis.

It is observed that piracy of software, music, movies, and many other technologies is common in many developing countries, and that their governments do not seem to have done enough to stem these piracy activities within their countries. In terms of the terminology in this paper, these governments choose a positive value of β that is less than one.

Proposition 2 *If $k_\beta = 0$, then the complete free-riding case exists, in which South always chooses no IPR protection, no matter what subsidy North picks. If condition C(i) is satisfied, the complete IPR Protection case will not exist.*

Proof. If $k_\beta = 0$, (23) reduces to

$$W^s_\beta = p' q^s \frac{\partial q^n}{\partial \beta} + f q^s - x^s p' \frac{\partial Q}{\partial \beta} > 0. \tag{25}$$

Condition (25) implies that an increase in β (or a decrease in IPR protection) is always beneficial, no matter what subsidy North has chosen. We thus have the complete free-riding case. If $\beta = 0$, condition (23) reduces to

$$W^s_\beta = p' q^s \sigma + f q^s - x^s p' \phi. \tag{26}$$

If condition C(i) is satisfied so that $\phi \geq 0$, then $W^s_\beta > 0$, no matter what subsidy North chooses. Thus at least a little loosening of the IPR protection is good. So the optimal value of β cannot be 0, i.e., the complete IPR Protection case does not exist. ■

In what follows we focus on the cases in which there is some free-riding, but it is not complete. In other words, we assume that the magnitude of k_β is sufficiently large so that for some values of s, government S chooses an optimal value of β that is positive but less than one. The reaction function $\beta = R^s(s)$ can be represented by curve CD in Figure 1 or 2. Its slope is given by

$$\left.\frac{\mathrm{d}s}{\mathrm{d}\beta}\right|_{\mathrm{CD}} = -\frac{W^s_{\beta\beta}}{W^s_{\beta s}}. \tag{27}$$

For the second-order condition, we assume that $W^s_{\beta\beta} < 0$. Thus the sign of the slope of South's reaction curve is equal to that of $W^s_{\beta s}$. Differentiate (23) with respect to s to give

$$\begin{aligned} W^s_{\beta s} &= p'\sigma q^s_k k_s + p'q^s(q^n_{kk}k_\beta k_s + q^n_k k_{\beta s} + q^n_{\beta k}k_s) + f'q^s k_s + f q^s_k k_s \\ &\quad + \beta f'' q^s k_\beta k_s + \beta f' k_\beta q^s_k k_s + \beta f' q^s k_{\beta s} \\ &\quad - p'\phi x^{s\prime} p' Q_k k_s - x^s p'(Q_{kk}k_\beta k_s + Q_k k_{\beta s} + Q_{\beta k}k_s). \end{aligned}$$

In general, the sign of $W^s_{\beta s}$ is ambiguous. Depending on the sign, two cases can be identified.

1. Whipping-with-a-Stick Case: $W^s_{\beta s} > 0$.
2. Bribing-with-a-Carrot Case: $W^s_{\beta s} < 0$.

The meaning of these two names will be explained later. These two cases are illustrated in Figures 1 and 2, respectively. In Figure 1, the reaction curve of South denoted by $R^s(s)$ is positively sloped, while in Figure 2, the curve is negatively sloped. In Figure 1, the reaction curves of both governments are positively sloped. By the usual "stability" condition, we assume that South's reaction curve is steeper than that of North.[8]

In both diagrams, the intersection point, N, between the two reaction curves depicts the Nash equilibrium (β^n, s^n).

[8] In the present one-shot game, stability of an equilibrium is of little meaning. However, by the correspondence principle, a stable equilibrium usually gives normal comparative static results. The assumed relative steepness of the curves will yield normal comparative static results.

4.3 Cross-country Effects of the Policies

We now examine how the welfare of a country is affected by the policy chosen by the other country. We first determine the effects of an increase in β on the welfare of North. Differentiate the welfare function of North in (14) with respect to β to give

$$\frac{\partial W^n}{\partial \beta} = p' q^n q^s_\beta - x^n p'(Q_k k_\beta + Q_\beta) - s k_\beta. \tag{28}$$

The derivative in (28) has three terms, which can be termed the *profit effect*, the *consumer effect*, and the *revenue effect*. The profit effect represents the effect of an increase in β (a loosening of the IPR protection) on firm N's profit, and it is negative. The consumer effect is the effect on the consumer surplus, and it is positive because an increase in β encourages the total production of the firms, thus driving down the price and improving consumer surplus. The revenue effect is due to the fact that an increase in β discourages R&D of firm N, thus saving North's subsidy expenditure.

Lemma 2. $\partial W^n / \partial \beta < 0$ when evaluated at $s = R^n(\beta)$.

Proof. When evaluated at $s = R^n(\beta)$, substitute (16) into (28) and rearrange the terms to give

$$\frac{\partial W^n}{\partial \beta} = \frac{f}{3}(x^n - 2q^n). \tag{29}$$

Note that with a lower marginal cost, firm N has a larger output than firm S has, implying that $2q^n > Q = x^n + x^s$, or $x^n < 2q^n$. So $\partial W^n / \partial \beta < 0$ in (29). ■

Lemma 2 implies that as long as North always chooses the optimal subsidy, it benefits from a tighter IPR protection in South. We then turn to the effect of North's subsidy on South's welfare. Differentiate the welfare function given in (22) with respect to s to give

$$\frac{\partial W^s}{\partial s} = (p' q^s q^n_k + \beta f' q^s - x^s p' Q_k) k_s. \tag{30}$$

Condition (30) shows that the effects of an increase in s on South's welfare work through a change in firm N's technology choice. The condition shows that the effects can be disaggregated into three terms. The first term represents the effect on firm S's revenue, and it is negative because of a rise in firm N's output and the resulting drop in the market price. The second term is the positive technology spillover effect. The third term is the increase in the country's consumer surplus because of a drop in the market price. It is assumed that the net effect is positive at all relevant values of β.[9]

Lemma 3. An increase in North's subsidy rate benefits South, $\partial W^s/\partial s > 0$, if (i) South always chooses its optimal β, or (ii) South's export is sufficiently small and if $\beta > 1/5$.

Proof. Consider first condition (i). The first-order condition (23) can be expressed as

$$W^s_\beta = \left(p' q^s q^n_k + \beta f' q^s - x^s p' Q_k\right) k_\beta + \left(p' q^s q^n_\beta - x^s p' Q_\beta + f q^s\right) = 0. \quad (31)$$

Because $p' q^s q^n_\beta - x^s p' Q_\beta + f q^s > 0$ and $k_\beta < 0$, (31) implies that $p' q^s q^n_k + \beta f' q^s - x^s p' Q_k > 0$. Substitute this result into (30). Noting that $k_s > 0$, We have the lemma. Now assume $q^s = x^s$. Condition (30) reduces to

$$\frac{\partial W^s}{\partial s} = \frac{q^s f'(5\beta - 1) k_s}{3}. \quad (32)$$

Condition (32) immediately gives the lemma. ■

Lemma 3 implies that if South always chooses the optimal IPR protection, it gains from an increase in North's subsidy rate.

5 North as a Leader

In this section, we examine some more policy options of North. Since it tends to benefit from a tighter IPR protection, the question is how it wants to get South to choose a lower value of β. The present analysis is related to the use of pressure by some developed countries on developing countries to have the latter groups of countries providing tighter IPR protection.

In the present paper, we argue that one of the options for developed countries (North) is to take the first move before developing countries (South) sets their IPR protection level. We want to argue that by doing so North can improve its welfare, and in some cases, can benefit South as well. The question is whether North can take the first move. In some cases, it can. The

[9] This assumption is satisfied if the consumption level is approximately equal to the production level in country S.

reason is that firm N has to conduct R&D and improve its technology first before spillover occurs. Even though we assume that the spillover takes place within a short period of time, R&D can take a much longer time. This long period of time will give South to choose a new IPR protection level, making it difficult for South to announce an irreversible commitment on β before the R&D process starts. This permits North to influence firm N's technology decision, giving South the time to respond with its IPR protection.

Let us use Figure 1 to illustrate our point. The Nash equilibrium is at point N. This means that if both governments choose their policies at the same time, North will choose s^n and South will choose β^s. Suppose instead North chooses s^s. This will affect firm N's R&D activities, and will choose the corresponding technology improvement factor, k. It is difficult for South to argue that it has chosen a fixed β^n before R&D starts because it will be easy for it to convert to β^s at the end of the R&D process. Any announcement before R&D starts that it has chosen β^n is not credible.

We thus modify the game described above to a four-stage game. In stage 1, North chooses the R&D subsidy. In stage 2, South chooses the IPR protection, or the value of β. In stage 3, firm N chooses the expenditure on technology improvement, k. In stage 4, both firms compete in a Cournot way. In the present game, North acts as a Stackelberg leader.

We now analyze the present game. First, note that stages 3 and 4 are the same as stages 2 and 3 in the previous game. Thus we do not need to repeat the analysis here. In stage 2, South chooses β, taking the subsidy rate chosen by North as given, to maximize its national welfare function given by (22). The solution describes South's reaction function, $\beta^* = R^s(s)$. To have a meaningful analysis here, it is assumed that neither the complete free-riding nor the complete IPR protection case exists, so that for relevant values of s South wishes to choose a positive β less than one.[10] South's reaction function is shown by the relevant curves in Figures 1 and 2.

In stage 1, North solves the following problem:

$$\max_s W^n(\beta, s) \quad \text{such that } \beta = R^s(s). \tag{33}$$

[10]As a matter of fact, the present analysis covers also the case in which of having the value of β at the Nash equilibrium is equal to one. In the present game, North has an incentive to get South to choose a lower β. As long as South is not very "keen" in setting $\beta = 1$ at the Nash equilibrium, government N can succeed.

The first-order condition is

$$\frac{\partial W^n}{\partial s} + \frac{\partial W^n}{\partial \beta}\frac{\partial R^s}{\partial s} = 0, \tag{34}$$

where $\partial R^s/\partial s$ is the reciprocal of the slope of curve $R^s(s)$ in Figures 1 and 2, which is given by (27). We showed earlier that the slope of curve $R^s(s)$ is ambiguous, depending on the sign of $W^s_{\beta s}$. Rearranging the terms in (34) gives

$$-\frac{\partial W^n/\partial s}{\partial W^n/\partial \beta} = \frac{\partial R^s}{\partial s}. \tag{35}$$

The left-hand-side of (35) is the reciprocal of the slope of an iso-welfare contour of North. The condition states that (for an interior solution) the optimal point occurs at a point of tangency between an iso-welfare contour of North and South's reaction curve.

In Figures 1 and 2, the optimal point for North is depicted at point S, at which an iso-welfare contour touches South's reaction curve. These two diagrams show two different cases, although in both cases South provides a tighter IPR protection, $\beta^s < \beta^n$. In the Whipping-with-a-Stick case in Figure 1, North chooses a subsidy lower than what it would do in the previous 3-stage game, $s^s < s^n$. As compared with the Nash equilibrium, North uses a lower subsidy to lead South to choose a tighter IPR protection.

In Figure 2, which shows the Bribing-with-a-Carrot case, the subsidy rate at point S is higher than that at point N, meaning that North uses a bigger subsidy to induce South to choose a lower β.

Proposition 3 *Suppose that North can choose the subsidy rate before South picks the degree of IPR protection. In the Whipping-with-a-Stick case ($W^s_{\beta s} > 0$), North uses a subsidy rate lower than that in a non-cooperative game to induce South to choose a tighter IPR protection. In the Bribing-with-a-Carrot case ($W^s_{\beta s} < 0$), North employs a subsidy rate higher than that in a non-cooperative game to induce South to pick a tighter IPR protection.*

The interesting question is how South's welfare is affected by North's taking the first move. To find out the answer to this question, we need to compare South's welfare in the above equilibrium with North as a Stackelberg leader with its welfare at the Nash equilibrium. By Lemma 3, when South always chooses the optimal IPR protection, it gains with an increase in North's subsidy rate. Thus in the whipping-with-a-stick case, South is hurt because North chooses a subsidy rate lower than the one at the Nash equilibrium. In the bribing-with-a-carrot case, South benefits from North's subsidy rate that is higher than the one at the Nash equilibrium. Graphically, in Figure 1 (the whipping-with-a-stick case), South's welfare is lower at point S than at point N. In Figure 2 (the bribing-with-a-carrot case), South's welfare is higher at point S than at point N.

6 Maximizing the World's Welfare

There have been suggestions that developing countries should tighten intellectual property rights. For example, the World Trade Organization (WTO) passed the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) during the Uruguay Round. The agreement is an attempt to narrow the gaps in the way these rights are protected around the world, and to bring them under common international rules. It establishes minimum levels of protection that each government has to give to the intellectual property of fellow WTO members. However, since most developed countries already have strong intellectual property rights protection, the agreement works mostly on developing countries.

6.1 The TRIPs

We want to examine the effects of such an agreement. Define the world's welfare as the sum of North and South's welfare:

$$W(\beta, s) = W^n(\beta, s) + W^s(\beta, s). \tag{36}$$

This function is maximized by choosing β while North is allowed to choose s to maximize its own welfare. We consider the following problem. In stage 1, an international organization such as the WTO chooses the level of IPR protection while at the same time North picks its subsidy rate.[11] In stage 2, firm N picks the technology improvement level, and in stage 3, both firms compete in a Cournot sense.

Since the last two stages are the same as before, the analysis in this subsection focuses on stage 1. In this stage, the problem of the WTO is to

[11] A slightly different game can be considered, in which the WTO chooses the level of IPR protection first and then country N picks its subsidy rate. It will produce a different equilibrium, but qualitatively the analysis is similar to what is presented in the paper.

maximize $W(\beta, s)$ by choosing β, taking the subsidy rate chosen by North as given. Its first-order condition is

$$W_\beta = \frac{\partial W^n}{\partial \beta} + \frac{\partial W^s}{\partial \beta} = 0. \tag{37}$$

The second-order condition is assumed. Condition (37) gives the reaction function of the WTO, $\beta = R^w(s)$. In Figure 3, it is represented by the curve EF, which is also labeled $R^w(s)$. The diagram shows also two iso-welfare contours of the world marked W_1 and W_2, with $W_2 > W_1$. The world's reaction curve is the locus of points on the iso-welfare contours with a slope equal to zero. The slope of this curve is given by

$$\left.\frac{\mathrm{d}s}{\mathrm{d}\beta}\right|_{\mathrm{EF}} = -\frac{W_{\beta\beta}}{W_{\beta s}}. \tag{38}$$

The second-order condition requires that $W_{\beta\beta} < 0$. Thus the sign of the slope of schedule $R^w(s)$ is the same as that of $W_{\beta s}$, which in general is ambiguous. The diagram shows the case in which the slope of the world's reaction curve is positively sloped.

The reaction function of North is the same as the one described by (16). In Figure 3, it is represented by curve $R^n(\beta)$. The intersection point, T, between these two curves gives the solution to the above problem. Let the solution be denoted by (β^t, s^t).

Since North is allowed to choose its own optimal subsidy, by Lemma 2, which states that $\partial W^n/\partial\beta < 0$, we have the following condition at the solution,

$$\frac{\partial W^s}{\partial \beta} > 0. \tag{39}$$

Assuming that $W^s(\beta, s)$ is concave, condition (39) implies that $\beta^t < \beta^n$. Furthermore, because North's reaction curve is positively sloped, we get $s^t < s^n$. We now have the following proposition:

Proposition 4 *If IPR protection is chosen to maximize the world welfare while North is allowed to choose its own subsidy rate, comparing with the Nash equilibrium, a tighter IPR protection and a lower subsidy rate will be chosen. South is hurt while North benefits.*

In terms of the world's welfare and the welfare of North, the present equilibrium is superior to the Nash equilibrium. However, the difficulty of carrying out such a policy is that South is hurt and thus will not have any incentive in tightening the IPR protection beyond the Nash equilibrium level. The present equilibrium cannot be ranked uniquely with the one in which North acts as a Stackelberg leader in the whipping-with-a-stick case, but it is inferior to the one in which North acts as a Stackelberg leader in the bribing-with-a-carrot case.

6.2 The Global Maximum

We now turn to another option for maximizing the world welfare. In addition to choosing the optimal level of IPR protection, an international organization (the WTO) also picks the right subsidy rate on R&D activities of firm N. In other words, we modify the previous three-stage game so that in stage 1 the WTO chooses β and s to maximize $W(\beta, s)$, which is defined by (36).

Our analysis focuses on stage 1. The first-order conditions are

$$W_\beta = \frac{\partial W^n}{\partial \beta} + \frac{\partial W^s}{\partial \beta} = 0 \tag{40a}$$

$$W_s = \frac{\partial W^n}{\partial s} + \frac{\partial W^s}{\partial s} = 0. \tag{40b}$$

Condition (40a) is the same as (37). As usual, the second-order condition is assumed. Condition (40b) guarantees that the optimal subsidy rate is chosen. Figure 3 shows the global optimal point, W. Let the solution be (β^w, s^w).

Let us try to compare point W with point N. Suppose that initially the countries choose the Nash equilibrium values (β^n, s^s). At this point, both countries are maximizing their own utility choosing their appropriate policy parameter, implying that $\partial W^s/\partial\beta = \partial W^n/\partial s = 0$. When evaluated at point N, Lemma 2 implies that $\partial W^n/\partial\beta < 0$, and Lemma 3 gives $\partial W^s/\partial s > 0$. Thus, at point N,

$$W_\beta = \frac{\partial W^n}{\partial \beta} < 0 \tag{41a}$$

$$W_s = \frac{\partial W^s}{\partial s} > 0. \tag{41b}$$

Conditions (41) imply that from point N a small rise in the subsidy rate and a small drop in β will improve the world welfare. Assuming a concave world welfare function, conditions (41) rule out the possibility that point W is lower and to the right of point N. This further implies that as compared with point N the global maximum requires a higher subsidy rate, a lower β, or both.

To get more information about the location of the global maximum point, W, we first note that the point must be a point on the contract curve between the two countries, i.e., it must be a point of tangency between one of North's iso-welfare contours and one of South's iso-welfare contours. Second, we also note that at any point on the contract curve, the iso-welfare contours are negatively sloped. In Figure 4, which shows the whipping-with-a-stick case, the contract curve must be above AN of North's reaction curve and ND of South's reaction curve. In this case, in moving from the Nash equilibrium to the global maximum there is a rise in s, a drop in β, or both. The diagram further implies that one of the countries, or possibly both of them, will gain from the process. In Figure 5, the contract curve must be in the region above AN of North's reaction curve but below ND of South's reaction curve. We can then conclude that to reach the global maximum there is a drop in β although s may go up or down. In this case, North must gain but South may gain or lose.

Proposition 5 *Suppose that the international organization (the WTO) can choose the IPR protection and subsidy rate to maximize the world welfare. In the whipping-with-a-stick case, the movement from the Nash equilibrium to the global maximum, there is a rise in* s, *a drop in* β, *or both. At least one of the countries gains. In the bribing-with-a-carrot case, the movement from the Nash equilibrium to the global maximum there is a drop in* β, *but the subsidy rate may go up or down. North gains but South may or may not be hurt.*

7 Concluding Remarks

In this paper, we examined the strategic behaviors of a developed country (North) and a developing country (South) concerning technology development, cross-country spillover, and competition between firms in the countries. The South and its own firms can free ride the technology improvement in the North. Since such technology spillover helps improves the technology and competitive edge of the firms in the South, the government in general will have little incentive in protecting intellectual property rights, as long as the technology in the North is concerned. However, as this paper argues, if the level of IPR protection can affect the level of technology chosen by the firms in the North, the South may want to choose a tighter IPR protection in order to induce the firms in the North to have a bigger improvement of their technology. The North, on the other hand, has an incentive to provide a subsidy to its own firms on R&D activities to correct the externality created due to the firms' neglecting the impacts of the technology improvement on consumer surplus. How much subsidy it will provide to the firms will depend on, among other things, the level of IPR protection announced by the government in the South.

This paper analyzes several games in which the North and the South compete in terms of technology subsidy and IPR protection. The base game is the one in which both of them choose their optimal policies at the same time. However, this paper argues that because R&D and technology improvement takes time, the North usually has the unique position of taking the first move in choosing its optimal subsidy rate. The South responds with its IPR protection. We showed that such IPR protection is tighter than what it would choose should both governments act at the same time. While the North gains by acting first, there are cases in which the South can get a welfare higher than what it achieves at a Nash equilibrium. Thus allowing the North to act first could provide Pareto improvement.

This paper also examines ways to improve the world welfare. However, it is argued that agreements like the TRIPs may be difficult to implement as it could help developed countries at the expense of the developing countries (as compared with the Nash equilibrium). Another policy that determines not just the IPR protection in the world and but also the subsidy rate in developed countries could be a better policy as it can lead the world to its global maximum.

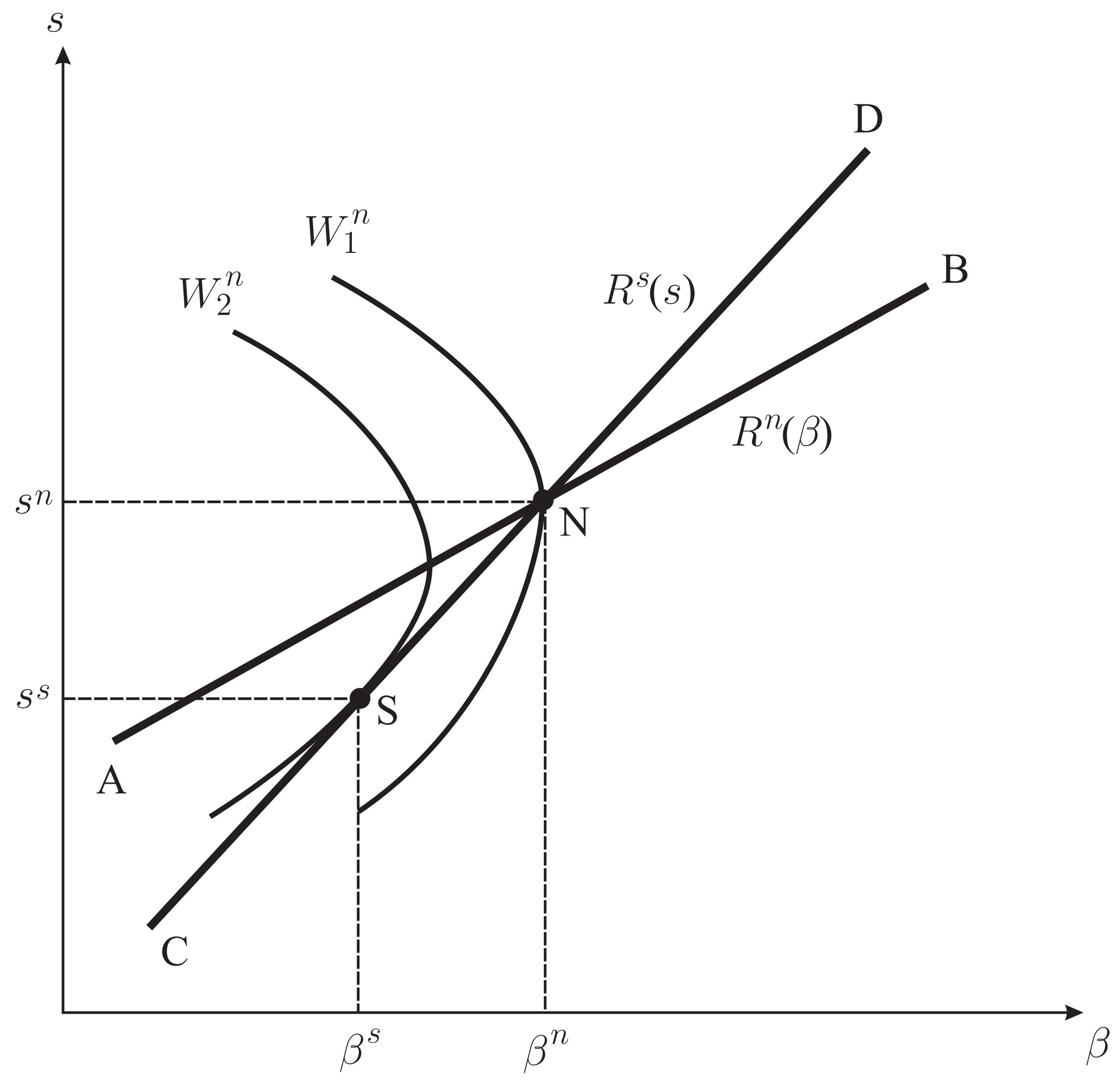

Figure 1

The Whipping-with-a-Stick Case

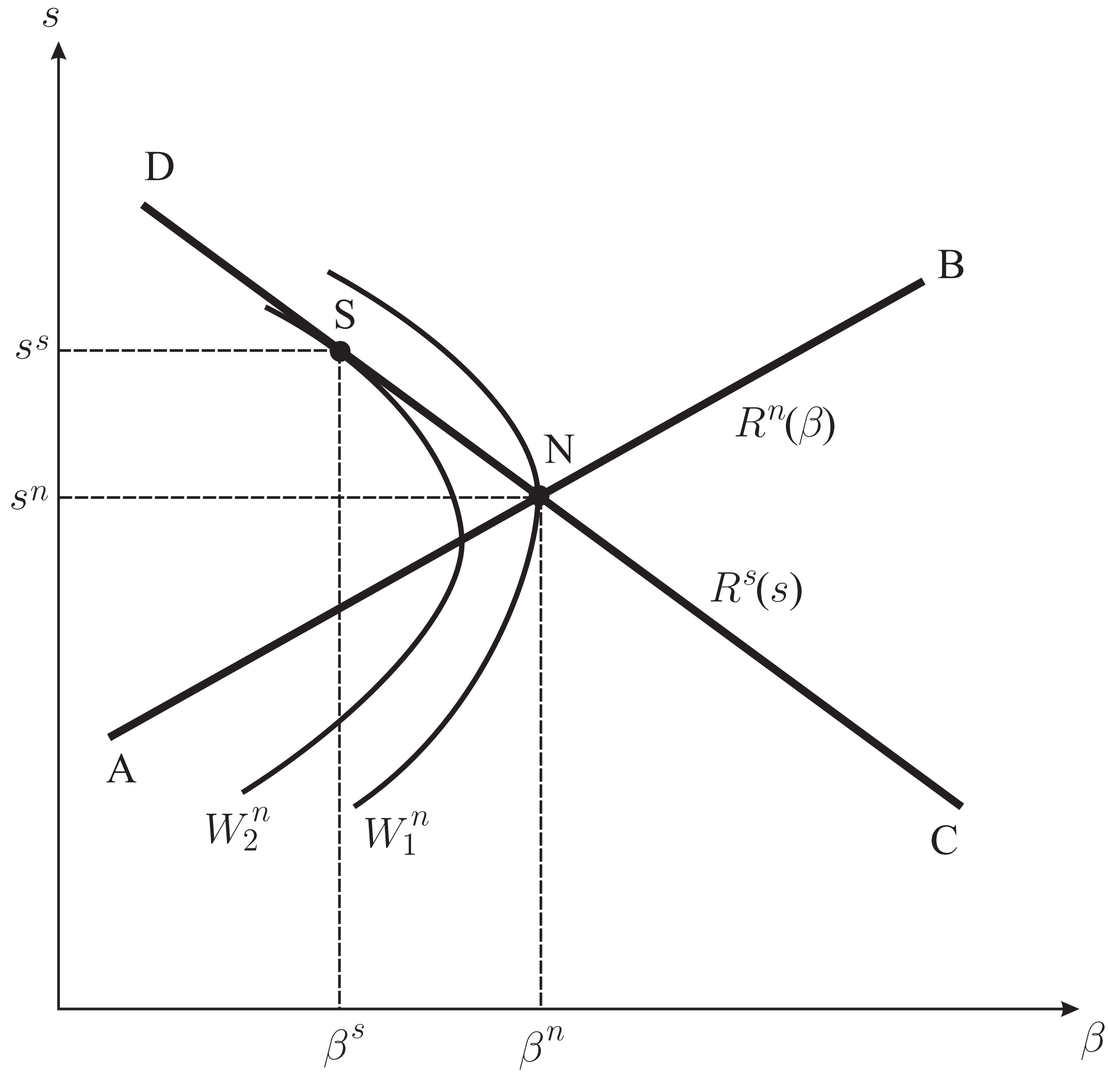

Figure 2

The Bribing-with-a-Carrot Case

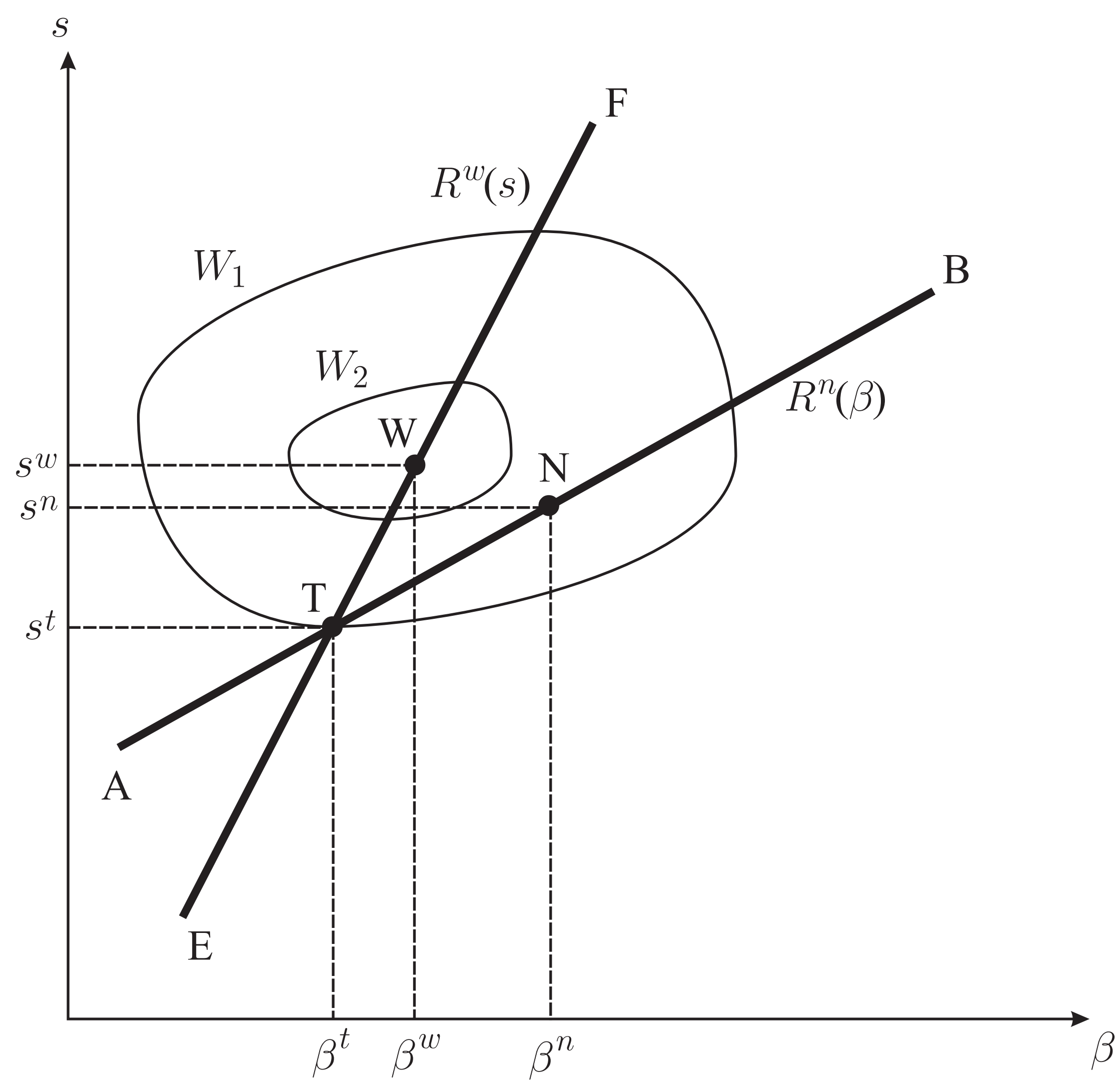

Figure 3

The World's Welfare

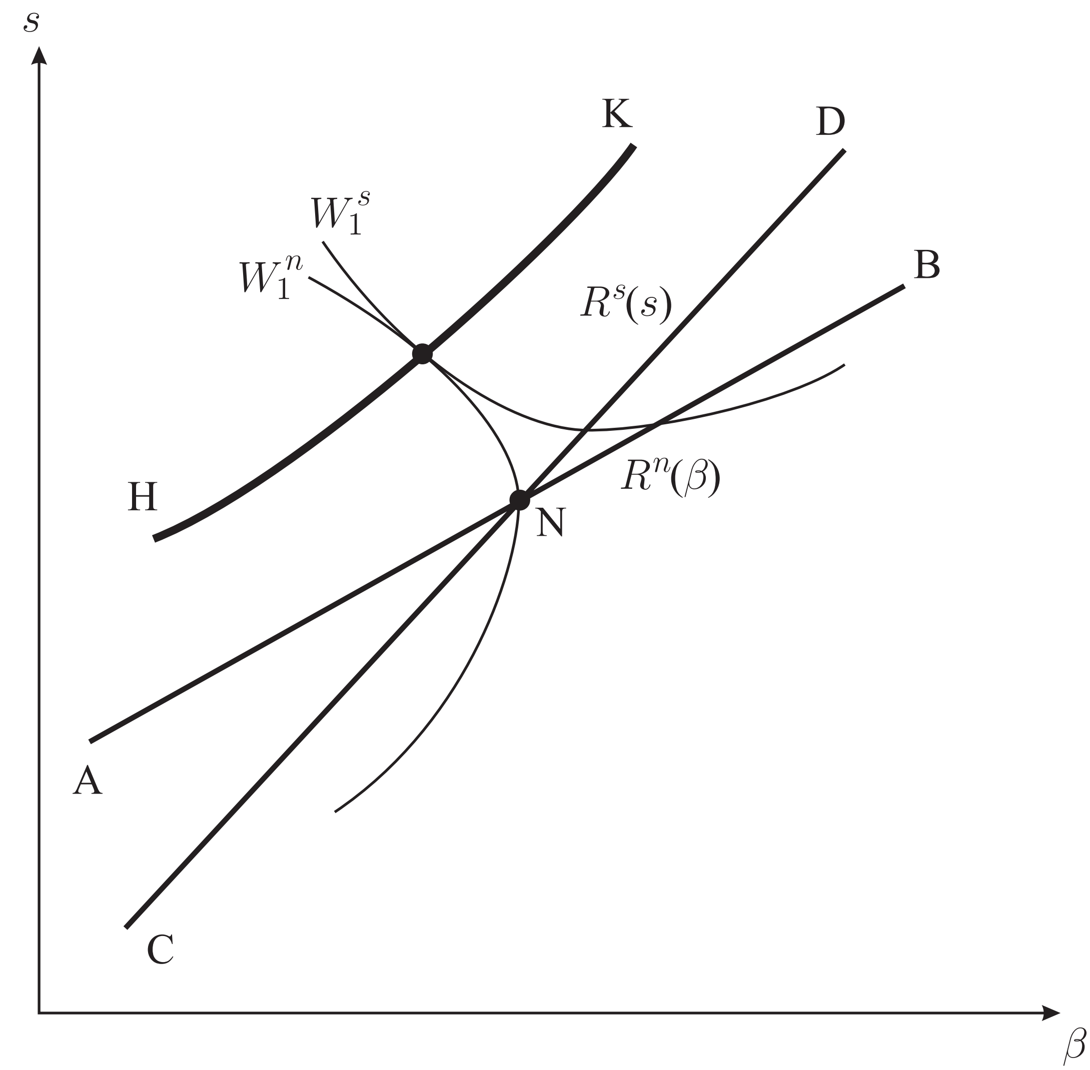

Figure 4

Contract Curve in the Whipping-with-a-Stick Case

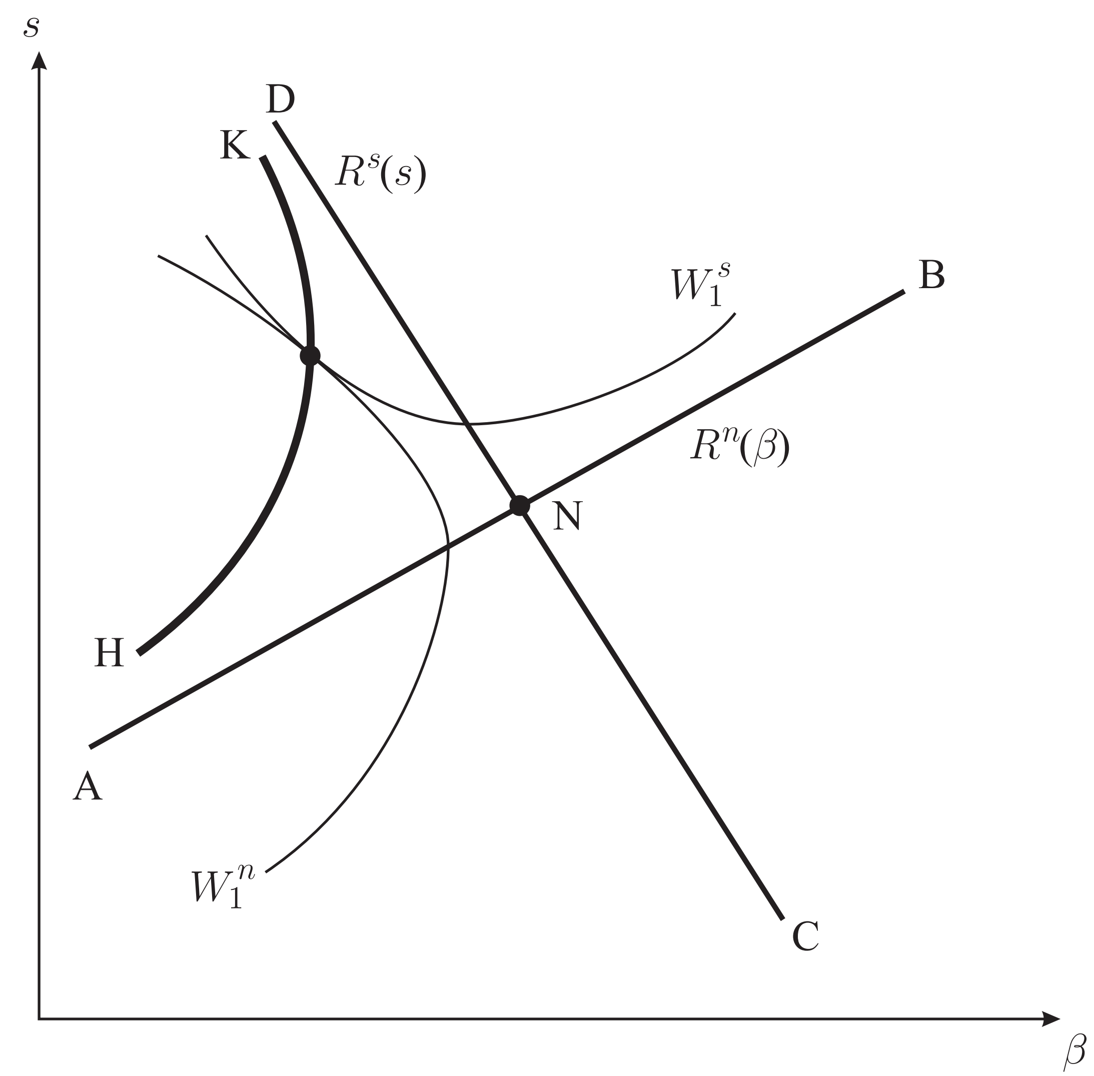

Figure 5

Contract Curve in the Sweetening-with-a-Carrot Case

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