The Welfare and Incentive of Stackelberg Competition in International Copyright

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Abstract

We study the incentive for international cooperation by analyzing a model of Stackelberg competition in copyright policy between two countries and comparing it with a cooperative model. It is found that one country, especially the small one, has an incentive to become a Stackelberg leader in a Stackelberg competitive game, as it gains higher national welfare than to cooperate; and that cooperation is globally preferable, as it leads to higher global welfare. This may help explain the fact that some small countries seem to lack the incentive to either participate in the international copyright system or enforce their copyright laws. This suggests that some incentive for international cooperation in copyright may have to come from sources outside copyright.

Keywords*: international copyright-policy making, Stackelberg competition vs. cooperation, welfare property, numerical analysis*

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1. Introduction

Copyright is a legal underpinning for the increasingly global information economy. There has been growing international cooperation in copyright. This can be seen from the various international copyright treaties. They include the Berne Convention first signed in 1886, the World Intellectual Property Organization (WIPO) established in 1967, the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPs) reached at 1994, and the WIPO Copyright Treaty signed in 1996. Through these treaties, signing countries cooperate and commit to a common minimal copyright policy, which most countries adopt as their actual copyright policy.

On the other hand, more international cooperation in copyright, especially in enforcing the treaties, is apparently desired and rigorously pursued by the United States and some other developed countries. This can be seen from the annual reports of the global state of intellectual property rights (IPR) protection and enforcement conducted by the Office of the United States Trade Representative (USTR) to encourage and maintain effective IPR protection and enforcement worldwide. For example, the 2009 report identified 46 countries that are reported to deny adequate and effective protection for IPR or deny fair and equitable market access for persons that rely on intellectual property protection (USTR, 2009).

Why do countries cooperate in copyright? Why do some countries seem to have inadequate incentive for such cooperation? These seemingly simple questions have not been subjected to rigorous economic analyses.

We study these questions through two models of international copyright. In a Stackelberg model, two countries compete in setting their copyright policies in a Stackelberg game: one country takes the copyright policy of the other country as given and reacts to it when this country sets its own copyright policy; and the other country considers the reaction of this country in setting the other country's policy. In the cooperative model, two countries cooperate to set a common copyright policy to pursue global welfare, in the way as in (Yuan and Domon, 2009).

We find that one country will have an incentive to pursue Stackelberg leadership in a Stackelberg game of copyright policy, as it gains higher national welfare than to cooperate. We also find that cooperation is globally preferable, as it leads to higher global welfare. This means that some incentive for international cooperation in copyright may have to come from sources outside copyright, such as in the forms of aid or favorable terms in other economic or political relations.

This study differs from extant copyright studies. Most copyright models assume a single copyright-policy maker and a single market for information goods with no international trade. Examples of such models include Novos (1984), Johnson (1985), Liebowitz (1985), Besen and Kirby (1989), Landes and Posner (1989), Yoon (2002), and Yuan (2005). Yuan (2009) studies two countries competing in a symmetric game in setting copyright policies. This paper differs by modeling asymmetric competition. Asymmetry may be natural as countries differ in the size of market for information goods, in the capability of their creative industries, etc.

This study differs from extant studies on international patent policy. First, Berkowitz and Kotowitz (1982) model the patent policy of a small country facing a world. However, it is not a game model, as the world does not react to the patent policy of the small country. Second, Scherer (2004) estimates the effect on global welfare of a uniform international patent policy versus that of weaker patent protection in poorer countries for pharmaceutical products. However, it does not model patent policy-making by national governments. Third, Scotchmer (2004) and Grossman and Lai (2004) develop two country models for patent policy. However, they both assume a single inventor per country and no interaction, substitutive or otherwise, among the invented products. Therefore, there is no competition either on the markets for these goods or in invention. This study differs in that creators engage in monopolistic competition on both domestic and foreign markets. This competition among creators better reflects the situation under copyright law, which allows creators to sell substitutive works without copying the fixed expressions of each other. The competition among creators has also been shown to be critical for optimal patent policy in the case of patent inventors (Palmer and Rafiquzzaman, 1986).

The rest of the paper is organized as follows: The next section develops the Stackelberg model of international copyright; the third section presents the results of the model, in comparison with those of the cooperative model. The paper then concludes. The mathematical procedures leading to the solutions are provided in the appendix.

2. The Stackelberg Model of International Copyright

2.1 The Stackelberg Model

Assume a world information economy composed of two countries. Each has a sector of creators and a market for information goods. A creator in either country develops original information products and sells copies of its products on its domestic and foreign markets.

The copyright policy of a country may be set up according to either the Stackelberg model described below or the cooperative model described in (Yuan and Domon, 2009). The policy adopted by a country applies to both domestic products and foreign products on the market of the country. Arbitrage across border is prohibited by a ban on parallel import, if prices of the same products differ on the two markets or copyright protection on one market expires before on the other.

The Stackelberg model can be described as a two-stage game. At the first stage, copyright authorities of the two countries play a Stackelberg game on copyright duration. At the second stage, creators of the two countries compete with each other on pricing, number of first-copy products, and entry to the markets to maximize their profits. Duration copyright protection, each creator is the sole seller of its products. Since copyright law allows creators to create and sell substitutive products without copying expressions of products of others, each creator competes monopolistically with other creators.

To solve the sub-game perfect equilibriums, creators' behaviors in stage two of the game are to be described first; the behaviors of the copyright authorities in stage one will be described thereafter.

Assume the following notations:

i, j: indices of creators of country 1 or 2;

n_k: number of creators of country k, k=1 ,2;

s_{ki}: number of first-copy products of creator i of country k, k=1, 2;

s_{k-i}: the vector of numbers of first-copy products of all creators other than i of country k, k=1, 2; the vector includes numbers of first-copy products of creators of the other country;

S: total number of first-copy products $S = \sum_{k=1}^{2} \sum_{i=1}^{n_k} s_{ki};$

$C_{ki}(s_{ki})$: creative cost of creator i of country 1, k=1, 2;

b: reproduction cost per copy of creators of both country 1 and 2;

p_{klit}: price per copy of products of creator i of country k in country l at time t, k=1, 2 and l=1, 2;

p_{kl-it}: vector of prices of products of all creators, other than that of creator i of country k in country l at time t, k=1, 2 and l=1, 2; the vector includes prices of creators of the country other than k in country l;

$d_{klit}(s_{ki}, s_{k-i}, s_{lj}, s_{l-j}, p_{kli}, p_{kl-i}, t)$: rate of demand for products of creator i of country k in country l at time t, k=1, 2 and l=1, 2;

cs_k: consumer surplus of country k, k=1, 2;

γ: social discount rate for consumers and creators in both countries;

T_k: copyright duration of country 1, k=1, 2.

The profit of creator i of country 1 is:

$$\pi_{1i} = \int_0^{T_1} (d_{11it}(p_{11it} - b)e^{-\gamma t} dt + \int_0^{T_2} (d_{12it}(p_{12it} - b)e^{-\gamma t} dt - c_{1i}(s_{1i}) \qquad (1)$$

The first term is the quasi-rent from selling its products on the market of country 1 during copyright duration of that country from time 0 to time T_1; the second term is the quasi-rent from selling on the market of country 2 during its copyright duration from time 0 to time T_2. The third term is the total creative cost of creator i creating s_{1i} number of first-copy products.

Similarly, the profit of creator i of country 2 is:

$$\pi_{2i} = \int_0^{T_1} (d_{21it}(p_{21it} - b)e^{-\gamma t} dt + \int_0^{T_2} (d_{22it}(p_{22it} - b)e^{-\gamma t} dt - c_{2i}(s_{2i}) \qquad (2)$$

A creator chooses prices and number of first-copy products to maximize profit. The first-order conditions are:

$$\frac{\partial \pi_{1i}}{\partial p_{11it}} = \frac{\partial \pi_{1i}}{\partial p_{12it}} = \frac{\partial \pi_{1i}}{\partial s_{1i}} = \frac{\partial \pi_{2j}}{\partial p_{21jt}} = \frac{\partial \pi_{2j}}{\partial p_{22jt}} = \frac{\partial \pi_{2j}}{\partial j} = 0 \qquad \forall \text{ i and j} \qquad (3)$$

A creator also decides whether to enter or stay on the market. The information product industries are assumed to be open. Therefore, in the long run, the marginal creator cannot make positive economic profits. That is:

$$\pi_{1i} \leq 0 \qquad \forall \text{ i} \qquad (4)$$

$$\pi_{2j} \leq 0 \qquad \forall \text{ j} \qquad (5)$$

If all creators in a country have the same technology, they all make the same profit. Then the non-binding case of π_{1i}<0 or π_{2j}<0 represents the situation when no creators of country 1 or country 2, respectively, actually enter the market; i.e., viable creative industry does not exist in the country.

The consumer surplus of country 1 is:

$$cs_1 = \sum_{i=1}^{n_1} \int_0^{\infty} \left(\int_b^{\infty} d_{11i} dp_{11it} \right) e^{-\gamma t} dt + \sum_{i=1}^{n_2} \int_0^{\infty} \left(\int_b^{\infty} d_{21i} dp_{21it} \right) e^{-\gamma t} dt$$

$$-\sum_{i=1}^{n_1}\int_0^{T_1}\left(\int_b^{p^*_{11it}} d_{11i}dp_{11it}\right)e^{-\gamma t}dt-\sum_{i=1}^{n_2}\int_0^{T_1}\left(\int_b^{p^*_{21it}} d_{21i}dp_{21it}\right)e^{-\gamma t}dt \qquad (6)$$

Where p^*_{11it} and p^*_{21it} are prices chosen by creator i of country 1 and creator i of country 2, respectively, on the market of country 1 during copyright protection. The first term is country 1's consumer surplus from all products of creators of country 1, if the products were priced at marginal reproduction cost b from the moment they are created; the second term is the surplus from products of creators of country 2, if the products were priced at reproduction cost b from the moment they are created; the third term is the loss of consumer surplus from products of creators of country 1 due to copyright protection, which lasts from time 0 to T_1; the fourth term is the loss of consumer surplus from products of creators of country 2 due to the same copyright protection.

Similarly, the consumer surplus of country 2 is:

$$cs_2=\sum_{i=1}^{n_1}\int_0^{\infty}\left(\int_b^{\infty} d_{12i}dp_{12it}\right)e^{-\gamma t}dt+\sum_{i=1}^{n_2}\int_0^{\infty}\left(\int_b^{\infty} d_{22i}dp_{22it}\right)e^{-\gamma t}dt$$

$$-\sum_{i=1}^{n_1}\int_0^{T_2}\left(\int_b^{p^*_{12it}} d_{12i}dp_{12it}\right)e^{-\gamma t}dt-\sum_{i=1}^{n_2}\int_0^{T_2}\left(\int_b^{p^*_{22it}} d_{22i}dp_{22it}\right)e^{-\gamma t}dt \qquad (7)$$

Where p^*_{12it} and p^*_{22it} are prices chosen by creator i of country 1 and creator i of country 2, respectively, on the market of country 2 during copyright protection. Here the demands are from the market of country 2; and copyright duration lasts from time 0 to T_2.

Assuming all creators in a country have the same technology, they all make zero economic profit at equilibrium. Social welfare is then the same as consumer surplus.

In the first stage of the game, the copyright authorities of two countries play a sub-game of Stackelberg competition in copyright duration. Note that the Stackelberg competition is between the copyright authorities of the two countries, not among creators. In the sub-game, country 1 moves first, sets a copyright duration T_1; country 2 reacts by choosing T_2 to maximize its national welfare, given the copyright duration T_1 set by country 1 and the behavior of creators under given T_1 and T_2:

$$\max_{T_2} cs_2 \tag{8}$$

S.t. (3)-(5), $T_2 \geq 0$, and T_1 given by country 1.

Since π_1 and π_2 in (3)-(5) evolve T_1, the solution of T_2 from (8) depends on T_1, which gives a reaction function of T_2 to T_1.

Country 1's problem is to choose T_1 to maximize the national welfare of country 1, given the reaction function of country 2 to its copyright policy, i.e.:

$$\max_{T_1} cs_1 \tag{9}$$

S.t. (3)-(5), $T_1 \geq 0$, and (8)

2.2 The Cooperative Model

The cooperative model is the same as in (Yuan and Domon, 2009). It differs from the Stackelberg model only in the first stage of the game, where country 1 and country 2 set a common copyright duration to maximize their collective global welfare, subject to the behavior of the consumers and creators as described in (3) to (5), i.e.:

$$\max_{T} cs_1 + cs_2 \tag{10}$$

S.t. (3)-(5) and $T_1 = T_2 \equiv T$[3].

Note that the choice of a country between Stackelberg competition and cooperation is determined by comparing the national welfare of the country under the two models.

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[3] A cooperative model without the constraint $T_1 = T_2$ is indeterminate as described in Domon and Yuan (2009).

3. The Results

To solve the models, one needs to further specify the demands of markets and cost of creators of the two countries.

3.1 Specification of Demand and Creative Cost Functions

The demand for information products differs from normal demand function for other products. The demand for the information products of a creator on a market depends on i) the price of the creator's products on the market, ii) the prices of other creators' products on the market, iii) the number of original products of this creator, iv) the number of original products of other creators, and v) time. The creative cost of a creator may include fixed cost to become a creator in the first place and a variable cost depending on the number of original products created. Expanding the demanding functions in (Yuan, 1997) to the two country setting, we assume the following specific demand and creative cost functions:

$$d_{11it} = D_1 s_{1i} \left(\sum_{j=1}^{n_1} s_{1j} + \sum_{j=1}^{n_2} s_{2j} \right)^{\alpha-1} p_{11it}{}^{-\delta} \prod_{j \neq i} p_{11jt}{}^{\frac{\beta}{n_1+n_2-1}} \prod_{j=1}^{n_2} p_{21jt}{}^{\frac{\beta}{n_1+n_2-1}} g_1(t) \tag{11}$$

$$d_{12it} = D_2 s_{1i} \left(\sum_{j=1}^{n_1} s_{1j} + \sum_{j=1}^{n_2} s_{2j} \right)^{\alpha-1} p_{12it}{}^{-\delta} \prod_{j \neq i} p_{12jt}{}^{\frac{\beta}{n_1+n_2-1}} \prod_{j=1}^{n_2} p_{22jt}{}^{\frac{\beta}{n_1+n_2-1}} g_2(t) \tag{12}$$

$$d_{21it} = D_1 s_{2i} \left(\sum_{j=1}^{n_1} s_{1j} + \sum_{j=1}^{n_2} s_{2j} \right)^{\alpha-1} p_{21it}{}^{-\delta} \prod_{j \neq i} p_{21jt}{}^{\frac{\beta}{n_1+n_2-1}} \prod_{j=1}^{n_1} p_{11jt}{}^{\frac{\beta}{n_1+n_2-1}} g_1(t) \tag{13}$$

$$d_{22it} = D_2 s_{2i} \left(\sum_{j=1}^{n_1} s_{1j} + \sum_{j=1}^{n_2} s_{2j} \right)^{\alpha-1} p_{22it}{}^{-\delta} \prod_{j \neq i} p_{22jt}{}^{\frac{\beta}{n_1+n_2-1}} \prod_{j=1}^{n_1} p_{12jt}{}^{\frac{\beta}{n_1+n_2-1}} g_2(t)$$

(14)

and creative cost functions:

$$g_k(t) = \begin{cases} 1 - \dfrac{t}{T_{0k}} & if \quad t < T_{0k}(1-\theta_k) \\ \theta_k & otherwise \end{cases} \qquad \text{k=1, 2} \tag{15}$$

and

$$c_{ki}(s_{ki}) = c_{0k} + a_k s_{ki}{}^{\rho_k} \qquad \forall \text{ i of country k, k=1, 2} \tag{16}$$

where $0<\alpha<1$, $\delta>1$, $\beta>0$, $0\leq \theta_1 <1$, $0\leq \theta_2 <1$, $\rho_1>1$, $\rho_2>1$, and D_1, D_2, T_{01}, T_{02}, $c_{01,}$ c_{02} and a_1 and a_2 are positive constants.

The main features in demand functions (11)-(14) are the following: There are five factors which affect the demand on a market for products of a creator multiplicatively. First, the total demand for all information products of all creators on a market increases with the total number of first-copy product. The parameter α is the demand elasticity to the total number of first-copy products[4]. It describes the consumers' preference for product variety. And $0<\alpha<1$ represents that the products are substitutes.

Second, the total demand is distributed among creators in proportion to their numbers of first-copy products, everything else being equal.

[4] To see the meaning of α, isolate the effect of total first-copy products S from those of other factors of market size, time, and prices. This is done by assuming D_1=D_2 =D_0, and $g_1(t)$=$g_2(t)$, and p_{kli}=p for k=1, 2 and l=1, 2 and any i. And recall that S=$\sum_{j=1}^{n_1} s_{1j} + \sum_{j=1}^{n_2} s_{2j}$. The total global demand becomes D=$\sum_{k=1}^{2}\sum_{l=1}^{2} d_{kl} = D_0 S^\alpha p^{-\delta+\beta}$. Therefore, $\frac{\partial D}{\partial S} = \alpha D_0 S^{\alpha-1} p^{-\delta+\beta} = \alpha \frac{D}{S}$. Thus, $\left.\frac{\partial D}{D}\middle/\frac{\partial S}{S}\right. = \alpha$, the elasticity of demand to total number of first-copy products.

Third, the demand for the products of a creator decreases with the price charged by the creator. The parameter δ is the price elasticity[5]. $\delta>1$ is necessary for the consumer surpluses to be finite.

Fourth, the demand for the products of a creator increases with the prices of other creators, reflecting that products of different creators are substitutes. The parameter $\beta>0$ is the cross-price elasticity.

Fifth, $g_1(t)$ and $g_2(t)$ reflect that the demands in the two markets decrease over time to residual levels of θ_1 and θ_2 of the original demands in time $T_{01}*(1-\theta_1)$ and $T_{02}*(1-\theta_2)$, respectively.

The markets in the two countries differ in the level of demand, D_1 and D_2, and the residual demand, θ_1 and θ_2, and the time it takes for the demands to drop to the residuals, $T_{01}(1-\theta_1)$ and $T_{02}(1-\theta_2)$. T_{01} and T_{02} are referred to as the economic life of information products on the two markets. Otherwise, each market treats all domestic and foreign products similarly. Consumers in the two countries are assumed to have the same price elasticity, cross-price elasticity, and preference for variety, as represented by the common parameters δ, β, and α, respectively.

The main features of the creative cost functions of (16) are the following: There are fixed costs to enter the creative industries in both countries, which are c_{01} and c_{02}, respectively. There are decreasing returns to scale in creation in both countries, as reflected in the parameters $\rho_1>1$, $\rho_2>1$, respectively. The levels of variable creative costs also depend on the

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[5] To see the meaning of δ and β using d_{11it}, aggregate the effects of the cross prices by assuming $p_{11j}=p_{21k}=p$ for $j\neq i$ and for any k. One has $d_{11it} = D_1 s_{1i} S^{\alpha-1} {p_{11it}}^{-\delta} \mathrm{p}^{\beta} g_1(t)$. Therefore, $-\frac{\partial d_{11it}}{d_{11it}} \Big/ \frac{\partial p_{11it}}{p_{11it}} = \delta$, the price elasticity and $\frac{\partial d_{11it}}{d_{11it}} \Big/ \frac{\partial \mathrm{p}}{\mathrm{p}} = \beta$, the cross price elasticity.

parameters a_1 and a_2, respectively, which will be referred to as the “per-product creative cost” parameters.

Creators within one country have identical creative costs. Creators of one country may differ from creators of the other country in fixed creative cost, per-product creative cost, and economies of creative scale, perhaps due to technological and general regulatory differences.

Given the multiplicativity of the factors affecting the demand, the common price elasticity, and the common reproductive cost of b for all products, it is easy to derive that creators set prices which are uniform for all products, all creators, at all moments of time:

$$p_{11it} = p_{12it} = p_{21j} = p_{22j} = p \equiv \frac{\delta}{\delta - 1} b \qquad (17)$$

Given the identical cost functions within one country, it can be derived that creators of one country all create the same number of first-copy products: $s_{1i} = s_{1j} \equiv s_1$ and $s_{2i} = s_{2j} \equiv s_2$, ∀ i and j.

In order to obtain consumer surpluses cs_1 and cs_2 and price p, sizes of creators, s_1 and s_2, total number of first-copy products S, and durations of T_1 and T_2, it is necessary to use computational procedure[6], given the values of the parameters in the demand and cost functions.

3.2 Baseline Solution

Assume the following parameter values:

$$[D_1, D_2, \alpha, \delta, \beta, b, T_{01}, T_{02}, \theta_1, \theta_2, \gamma, c_{01}, c_{02}, a_1, a_2, \rho_1, \rho_2] =$$

[6] Computational procedure is commonly used in physics and biology as most real physical or biological systems are not solvable analytically, see, e.g., Harrison (2001). It is also increasingly used in economic and social sciences. See Judd (1998) for an introduction.

$[7*10^6\ 7*10^6\ 0.3\ \ 2\ \ 0.5\ \ 5\ \ 100\ 100\ \ 0.001\ 0.001\ 0.05\ 3*10^5\ 3*10^5\ 10^4\ 10^4\ 1.2\ 1.2\ ]$

Table I shows the numerical solution computed for the Stackelberg model, as compared to the cooperative model.

Table I. Result of Stackelberg Model as Compared to the Cooperative Model

	T_1	T_2	s_1	s_2	S	cs_1($B)	cs_2 ($B)	W($B)
Stackelberg	0	14	62	62	4,935	0.91	0.64	1.55
Cooperative	14	14	64	64	13,281	0.86	0.86	1.72

Given the above parameter values, the Stackelberg leader does not provide copyright protection. The Stackelberg follower provides 14 years of copyright protection. Under the cooperative model, both countries provide 14 year protection, the same as the Stackelberg follower. The sizes of the creators in country 1 and country 2 under the Stackelberg model are both 62 first-copy products per creator, smaller than the 64 number under the cooperative model. The total number of first-copy products is 4,935 under the Stackelberg model, fewer than the 13,281 number under the cooperative model; under the Stackelberg model, country 1, the Stackelberg leader, achieves national welfare of $0.91 billion, higher than the $0.86 billion under the cooperative model; country 2, the follower, has a national welfare of $0.6 billion, lower than the $0.86 billion under the other model; global welfare is $1.55 billion, lower than the $1.72 billion under the cooperative model.

The baseline result suggests Stackelberg competition leads to under-protection of copyright, under-supply of original information products, and loss of global welfare.

Figure 1 shows that the above solution is optimal for the individual creators and individual countries, given the behavior of other creators and the other country. First, if a creator in either country deviates from the optimal size of 62 first-copy products, the creator will incur a loss, given that the two countries adopt their respective optimal copyright duration of 0 and 14. Second, if country 2 deviates from its optimal duration of 14 years, the welfare of the country will be lower than its maximum of $0.64 billion, given that country 1 adopts its optimal duration of zero copyright protection of the Stackelberg model. Third, if country 1 deviates from its optimal copyright duration of 0 years, i.e. longer than zero duration, its national welfare will be lower than its maximum of $0.91 billion, given that country 2 always adjusts its copyright duration in reaction to the duration of the country 1.

Note that the Stackelberg leader does not always provide 0 years of protection. For example, if the parameter D_1 changes to $2*10^7$ and other parameters retain their baseline values, the solution of the Stackelberg model becomes that in Table II, compared with the cooperative model:

Table II. Result of Stackelberg Model as Compared to the Cooperative Model

	T_1	T_2	s_1	s_2	S	cs_1 ($B)	cs_2 ($B)	W($B)
Stackelberg	2	8	63	63	6,076	2.62	0.78	3.39
Cooperative	14	14	65	65	33,938	3.25	1.14	4.39

In this case, both the leader and the follower provide positive but shorter duration of protection than under the cooperative model. And they both get lower national welfare than under the cooperative model.

3.3 Does Stackelberg Competition Always Lead to Lower Global Welfare?

In the baseline result, the Stackelberg model leads to lower global welfare relative to the cooperative model. Does Stackelberg competition always lead to lower global welfare? A positive answer would mean that cooperation is the globally preferable mechanism for international copyright-policy making.

To answer this question, we compare global welfare across the two models at various parameter values. First, change the values of one parameter, keeping the other parameters at their baseline values, re-solve the models and compute the differences in global welfare between the models. The results are shown in Table III.

Table III: Percent Decrease of Global Welfare of Stackelberg Model from Competitive Model

	Parameter Range	**% Global Welfare Loss**	**% Loss of First-copy Products**
$D_1(\times 10^6)$	1~100	0.5~22.4	17.4~82.1
$D_2(\times 10^6)$	1~100	0.1~22.4	9.2~82.1
α	0.1~0.492	2.3~24.1	53.5~74.4
δ	1.2~4	9.8~11.8	62.6~64.5
β	0.1~0.9	9.8~9.8	62.8~62.8
b	1~50	9.8~9.8	62.8~62.8
T_{01}	1~1000	0~12.2	4.4~68.1
T_{02}	1~1000	7.7~22.4	57.4~82.1
θ_1	0.0001~0.3	9.8~9.8	62.8~62.8
θ_2	0.0001~0.3	9.7~9.8	62.7~62.8
Γ	0.0002~0.3	9.8~9.8	62.8~62.8
$c_{01}(\times 1000)$	19.860~10000	9.8~9.8	62.8~62.8
$c_{02}(\times 1000)$	19.860~10000	9.8~9.8	62.8~62.9
$a_1(\times 1000)$	6.37~15.94	9.8~9.8	62.8~62.8
$a_2(\times 1000)$	6.04~15.94	9.8~9.8	62.8~62.8
ρ_1	1.152~1.2624	9.8~9.8	62.8~62.9
ρ_2	1.152~1.26	9.8~9.8	62.8~62.8

Table III shows that global welfare under the Stackelberg model is lower than that under the cooperative model for all changes of the individual parameter values. The loss by the Stackelberg model is always positive. The last column also shows first-copy products are lower under the Stackelberg model for all changes of the individual parameter values.

Second, draw random values of the parameters from the 17-dimensional area described by the ranges of the values of the 17 parameters in the second column of Table III and re-solve the models. For the 99 sets of random values of the parameters, the solutions of both models are successfully computed. For all 99 sets of random parameter values, global welfare is lower under the Stackelberg model than that under the cooperative model. The percent loss of global welfare is between 0.04% and 43.88%. Similarly, supply of original information products is lower under the Stackelberg model. The percent decrease of first-copy products is between 0.53% and 90.45%.

In summary, Stackelberg model leads to lower global welfare and under-supply of first-copy information products relative to the cooperative model.

Note that this result may not be surprising. Usually, firms earn higher profits when they cooperate than when they engage in Stackelberg competition. The difference is that, in the firms' case, cooperation may damage social welfare and is often prohibited. In our case, cooperation leads to higher global social welfare and, therefore, is the more preferable mechanism for international copyright policy-making.

3.4 Do Individual Countries Have the Incentives to Cooperate?

Given that Stackelberg competition leads to loss of global welfare, one wonders whether individual countries have the incentive to avoid Stackelberg competition. The incentive for a country to choose between cooperation and Stackelberg competition depends on the relative national welfare of the country under the two models. If there is a decrease in national welfare for a country under the Stackelberg model relative to that under the cooperative model, the country will have the incentive to choose cooperation over Stackelberg competition, and vice versa.

Compute national welfare under the two models for various values of the parameters. Table IV shows the ranges of percent decrease of national welfare by Stackelberg competition from cooperation, when values of individual parameters change and other parameters remain at their baseline values.

Table IV shows that, first, the Stackelberg leader sometimes prefers Stackelberg competition over cooperation. As the value of individual parameters changes in the ranges listed in the table, the decrease of national welfare of country 1, the leader, under the Stackelberg competition over cooperation can be positive or negative, such as for changes of the parameters D_1, D_2, T_{01}, and T_{02}. Therefore, in general, the Stackelberg leader sometimes gains national welfare under Stackelberg competition relative to cooperation. For 70 sets of the 99 computed sets of random parameter values, the Stackelberg leader has higher national welfare than that under cooperation; for 29 sets, it has lower national welfare.

Table IV: Percent Decrease of National Welfare of Stackelberg Model from Cooperative Model

	Parameter Range	**Country 1**	**Country 2**
$D_1(\times10^6)$	1~100	**-34.9~21**	5.6~40.3
$D_2(\times10^6)$	1~100	**-38.8~21.5**	2.9~40.4
α	0.1~0.492	-6.2~-0.6	7.7~48.9
δ	1.2~4	-22~-6.1	25.7~45.7
β	0.1~0.9	-6.2~-6.1	25.7~25.8
b	1~50	-6.3~-6.1	25.7~25.8
T_{01}	1~1000	**-93.6~1.1**	2.2~26.6
T_{02}	1~1000	**-14.3~25.6**	9.7~26.7
θ_1	0.0001~0.3	-6.2~-5.9	25.7~25.7
θ_2	0.0001~0.3	-6.4~-6.2	25.7~25.7
Γ	0.0002~0.3	-6.2~-6.1	25.7~25.7
$c_{01}(\times1000)$	19.860~10000	-6.2~-6.2	25.7~25.7
$c_{02}(\times1000)$	19.860~10000	-6.2~-6.1	25.7~25.7
$a_1(\times1000)$	6.37~15.94	-6.2~-6.2	25.7~25.7
$a_2(\times1000)$	6.04~15.94	-6.2~-6.1	25.7~25.7
ρ_1	1.152~1.2624	-6.2~-6.1	25.7~25.7
ρ_2	1.152~1.26	-6.2~-6.2	25.7~25.7

Second, Stackelberg follower prefers cooperation over Stackelberg competition. As the individual parameters change in the above ranges, the decrease in national welfare of country 2 remains positive. That is, the Stackelberg follower loses national welfare relative to that under cooperation. For the 99 computed sets of random parameter values, the percent decrease of national welfare of country 2 by the Stackelberg model from that under the cooperative model is between 1.50% and 54.58%.

In summary, a country may prefer Stackelberg competition by pursuing Stackelberg leadership, in spite of the higher global welfare under cooperation. The Stackelberg follower prefers the cooperative model, in consistence with higher global welfare under cooperative model.

This implies that all countries do not have the incentive to cooperate in copyright. Some incentives for cooperation may have to come from sources outside copyright. Obviously many sources of such incentives are possible, as countries engage in many different relationships. Since global welfare is higher under cooperation, worthwhile incentive can be found to induce countries away from Stackelberg competition and into cooperation. One way to do this is to transfer some welfare from the country which achieves higher increase in national welfare under the cooperative model to the country which achieves a lower increase in national welfare. Since global welfare is always higher under the cooperative model, such transfer, in principle, can be found to make all countries better off under the cooperative model than under Stackelberg model. Other possible incentives may include favorable terms in other economic or political relations.

Note that it may be possible, at least theoretically, to avoid using incentives outside copyright if countries play an indefinitely repeated game of choosing between cooperation or Stackelberg competition. Using the baseline solution as an example, the two countries can be considered playing a Prisoner's Dilemma shown in Table V:

Table V. Payoffs in Prisoner's Dilemma of Cooperation or Stackelberg Competition

(Country 1 welfare, country 2 welfare)		Country 2	
		Stackelberg Leader duration (0 years)	Cooperative Duration (14 years)
Country 1	Stackelberg Leader duration (0 years)	(0, 0)	(0.91, 0.64)
	Cooperative Duration (14 years)	(0.64, 0.91)	(0.86, 0.86)

In this game, each country has the incentive to defect from cooperation to the pursuit of Stackelberg leadership. Such defection may be avoided if the game is repeated indefinitely and defection is punished by defection. However, since it may be difficult for countries to change the duration of copyright freely and to maintain credibility of the copyright law with creators at the same time, payment or other sources of incentive outside copyright may have to be used in practice.

Finally, note that Stackelberg leadership may also dominate another possible competitive strategy. For example, with the baseline parameters, a country pursuing a symmetric competitive game as in (Yuan, 2009) will obtain national welfare of $0.80 billion, lower than the $0.91 billion obtained by pursuing Stackelberg leadership. In the case, Stackelberg competition also leads to worse global welfare than the symmetric competition ($1.55 billion vs. $1.60 billion.)

3.5 How Do the Incentives Change with Market and Technology Conditions?

Given that a country may pursue Stackelberg leadership at the expense of global welfare, it is helpful to further identify what kind of country may tend to do so. Since countries may differ in the size of their markets and in technology of creation, we investigate the effects of these differences on the incentive to become a Stackelberg leader.

3.5.1 The Effect of the Size of Market

The parameter D_1 or D_2 represent the size of the market of country 1 and 2, respectively. The effect of changing D_1 while retaining the baseline value for the other parameters, is shown in Figure 5-10.

The figures show that the incentive for a country to pursue Stackelberg leadership increases when the size of the market of the country decreases. In Figure 5, when $D_1=10^6$, relative to $D_2=7*10^6$, country 1 gains 35% in national welfare by pursuing Stackelberg leadership relative to cooperation; when D_1 increases to the same level as D_2=7*10^6, the gains reduces to 6%; the gain reduces to 0 when D_1 increases to about 9*10^6. When D_1 further increases, country 1's national welfare becomes lower than that under the cooperative model.

This result may be understood as follows. The copyright authority of each country chooses copyright duration to balance incentivizing creation of information goods and letting its consumer to enjoy created goods. In a two-country setting, the two copyright authorities play a game of chicken in maintaining that balance. A bigger country with higher demand for information goods has more to lose if there is not enough incentive for creation and not enough information products are created. Understanding this, the small country plays the Stackelberg leader and sets a low or zero copyright duration. The larger country is then forced to react by setting a longer copyright duration, bearing the heavier or full cost of copyright protection to provide the incentive for creation. This is reflected in Figure 9. Especially, when the leader is very small relative to the follower, the leader provides no copyright protection; the follower provides long protection as under the cooperative model. The big follower bears the full cost of copyright protection and small leader lets its consumers to fully enjoy the information goods brought by the protection by the big follower.

Figure 7 shows the percent losses of global welfare and first-copy information products decrease when the size of the market of the leader decreases. That means that smaller country causes less harm globally, although it has stronger incentive to play Stackelberg leadership. Or it's more harmful for a big country to play Stackelberg leadership rather than cooperate.

The above result is also shown by effects of market size of the follower, D_2. Figure 11-16 show the effect of D_{02}. As D_{02} becomes bigger, i.e., D_{01} becomes relatively smaller, the incentive for country 1 to be a Stackelberg leader increases but the losses in global welfare and supply of original information become less severe.

The effects of economic life of information products and residual demand of information products, T_{01} and T_{02}, θ_1, and θ_2 are found to be similar to those of D_{01} and D_{02}. A longer economic life of information products on a market or a larger residual demand is equivalent to a higher level of demand.

In summary, the percent gain of national welfare by becoming a Stackelberg leader increases when the size of the country decreases. Smaller country is more inclined to become a Stackelberg leader; larger country tends more to cooperate in international copyright.

This result seems to be consistent with some of the current and historical empirical facts in international copyright. First, some countries with small markets for information goods currently do not provide copyright protection. Such countries include Eritrea, San Marino, Turkmenistan, Laos, and Afghanistan. Second, as reported in the literature (e.g., Domon and Nakamura, 2007) and seen during field trips by the authors, although small developing countries, such as Vietnam and Colombia, may have copyright laws in the books, these laws are hardly enforced, effectively making copyright duration in these countries near zero. Third, the U.S. did not provide international copyright protection for over a century before 1891, when its market for information goods was small, relative to those in England and Europe. It started to provide copyright protection to foreign works since 1891, after the market of the U.S. had grown.

3.5.1 The Effect of Creative Technology

The parameters c_{01}, a_{01}, ρ_1, c_{02}, a_{01}, and ρ_2 describe the creative technology of creators in the two countries. They represent fixed creative cost, per-product creative cost, and diseconomies of creative scale of creators in the two countries, respectively.

Changes in creative costs have only marginal effect on the differences in national welfare of the leader and the follower and on the differences in global welfare and first-copy products between the two models. This is shown in Figure 17-22 and Figure 23-28 for the case for c_{01} and c_{02}. As c_{01} or c_{02} changes from 19,860 to 10^7, the difference between the two models in national welfare, global welfare, supply of original information products, and copyright durations are all in the order of hundredth of a percent point. The effects of a_{01}, a_{02}, ρ_1, and ρ_2 are in the same order of magnitude, when these parameters change across the intervals of [6,370~15,940], [6,040~15,940], [1.152~1.262], [1.152~1.262], respectively.

The marginal effects of creative costs across the models may be understood as follows. With open creative industries, creative cost parameters do not enter directly into the objective function of consumer surplus for the copyright authorities, unlike the demand parameters. The cost parameters affect copyright policy through their effects on consumer welfare, which is affected through the effects on behavior of creators. Since each country gives national treatment to creators of foreign creators, change of creative cost parameters in either country may have similar effects on copyright policies across the two countries. This similarity in effect of creative cost across countries make the Stackelberg model more similar to the cooperative model, which has the global welfare function as the common objective functions of the two copyright authorities. Therefore, the Stackelberg model and the cooperative respond to the changes in the creative costs similarly, leaving the difference between the two models to change little with changes in these parameters. Figure 53-58 show that the changes in creative costs lead to significant but similar effects on national welfare of country 1 in both models.

The effects on optimal duration of copyright of creative costs are also marginal. This is shown in Figure 21, 22, 27, and 28. This may be understood as follows. First, the increase in creative cost of a country has two effects in opposite directions on the duration of copyright:

On the one hand, higher creative costs mean that information products are less desirable to the societies as a whole, which calls for lower incentive for creation and shorter copyright durations. On the other hand, higher creative costs mean lower profits for creators and are themselves disincentives for creators, which reduce the need for shortening copyright protections. These two effects tend to cancel each other. Second, when the creative costs in a country decrease, creators of this country may simply take over market shares from creators of the other country and vice versa. Therefore, the impact of the change in creative costs on copyright policy and consumer welfare may be small.

Note that changes of creative costs in the country with higher creative costs have no effect on market outcome, as long as the creative costs in the country remain higher than in the other country such that its creators are not on the market.

Finally, the incentive for pursuing Stackelberg leadership increases with price elasticity, δ; it changes with consumer preference for variety, α, non-monotonously; the effects of the cross-price elasticity, β, social discount rate, γ, and reproduction cost, b, on the incentive to lead are marginal. These are shown in Figure 29-34.

In summary, changes in creative costs have little effect on the difference between Stackelberg competition and cooperation.

4. Conclusion

We developed and simulated a Stackelberg competitive model of international copyright and compared it to a cooperative model. The result suggests that all countries do not have the incentive to cooperate in international copyright, although cooperation always leads to higher global welfare. Instead, a country, especially a small one, may have the incentive to be a Stackelberg leader, as it gains higher national welfare than to cooperate in copyright policy-making.

The result may explain the phenomenon that while international cooperation in copyright is very much desired and rigorously pursued by some countries, such as the U.S., other countries, such as Eritrea or Vietnam, seem to lack the motivation either to participate or enforce their copyright laws. The result further suggests that some incentives may have to come from sources outside copyright to induce some countries, i.e., the small ones, to choose cooperation over Stackelberg competition in international copyright-policy making.

References

Besen, S.M. and S.N. Kirby (1989). Private copying, appropriability and optimal copying royalties. *Journal of Law and Economics* 32 (2), 255–280.

Domon, K. and K. Nakamura (2007). Unauthorized Copying and Copyright Enforcement in Developing Countries: A Vietnam Case Study. *Review of Economic Research on Copyright Issues* 4(1), 87-96.

Grossman, G.M. and L.C. Lai (2004). International Protection of Intellectual Property. *American Economic Review* 94, 1635-53.

Harrison, P. (2001). *Computational Methods in Physics, Chemistry and Biology: An Introduction*. John Wiley & Sons, New York.

Johnson, W.R. (1985). The economics of copying. *Journal of Political Economy* 93 (1), 158–174.

Judd, K. L. (1998). Numerical Methods in Economics. The MIT Press.

Landes, W.M. and R.A. Posner. (1989). An economic analysis of copyright law. *Journal of Legal Studies* 18 (2), 325–363.

Lichtenberg, F.R. and T. Philipson (2002). The Dual Effects of Intellectual Property Regulations: Within and Between Patent Competition in the US Pharmaceuticals Industry. *Journal of Law & Economics*. 45; 643-72.

Liebowitz, S.J. (1985). Copying and indirect appropriability: photocopying of journals. *Journal of Political Economy* 93 (5), 945–957.

Novos, I.E. and M. Waldman (1984). The effects of increased copyright protection: an analytic approach. *Journal of Political Economy* 92 (2), 236–246.

Palmer, J. and M.H. Rafiquzzaman (1986). The Scope and Duration of the Patent Right and the Nature of Research Rivalry. *Research in Law and Economics* 8; 91-120.

Scherer, F.M. (2004). A Note on Global Welfare in Pharmaceutical Patenting. *The World Economy* 27; 1127-42.

Scotchmer, S. (2004). The Political Economy of Intellectual Property Treaties. *The Journal of Law, Economics, and Organization* 20; 415-37.

Office of the United States Trade Representative (USTR) 2009. *2009 Special 301 Report*. April 30. http://www.ustr.gov/sites/default/files/Full%20Version%20of%20the%202009%20SPECIAL%20301%20REPORT.pdf

Yoon, K. (2002). The optimal level of copyright protection. *Information Economics and Policy* 14 (3), 327–348.

Yuan, Y. (1997). *Essays on Internet Business and Markets for Digital Information.* Doctoral Dissertation, Carnegie Mellon University.

Yuan, M. Y. (2005). Does decrease in copying cost support copyright term extension? *Information Economics and Policy* 17 (4), 471-494.

Yuan, M. Y. (2009). “Should Small and Large Information Economies Have the Same Duration of Copyright?” *Review of Economic Research on Copyright Issues*, vol. 6(1), pp. 13-33.

Yuan, M. Y. And K. Domon (2009). The Incentives for Cooperation in International Copyright: Comparing Cooperative and Competitive Models. *SERCI Annual Congress*, Berkeley California, July 9th-10th.

Figure 1-4: Optimality of Baseline Solutions of the Stackelberg Model

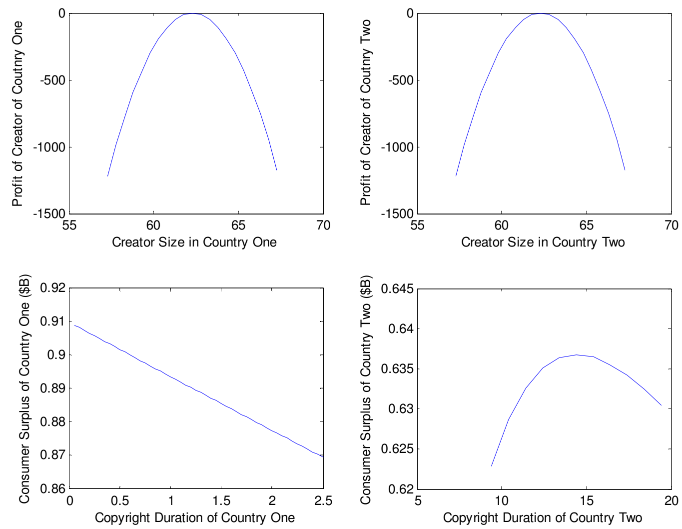


Figure 5-10: Effect of Size of Market of Country 1

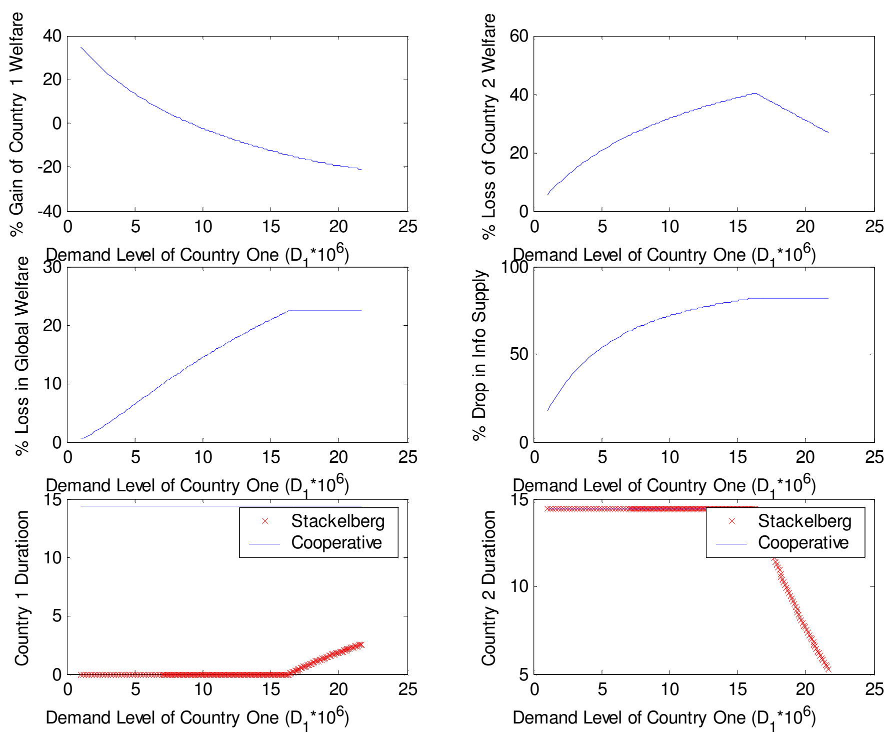


Figure 11-16: Effect of Size of Market of Country 2

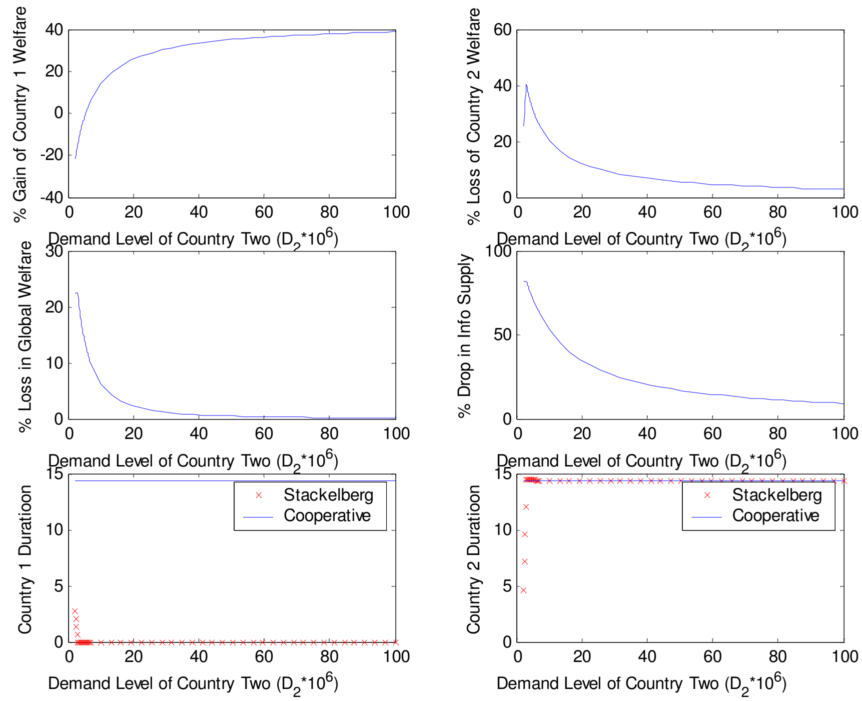


Figure 17-22: Effect of Fixed Creative Cost in Country 1

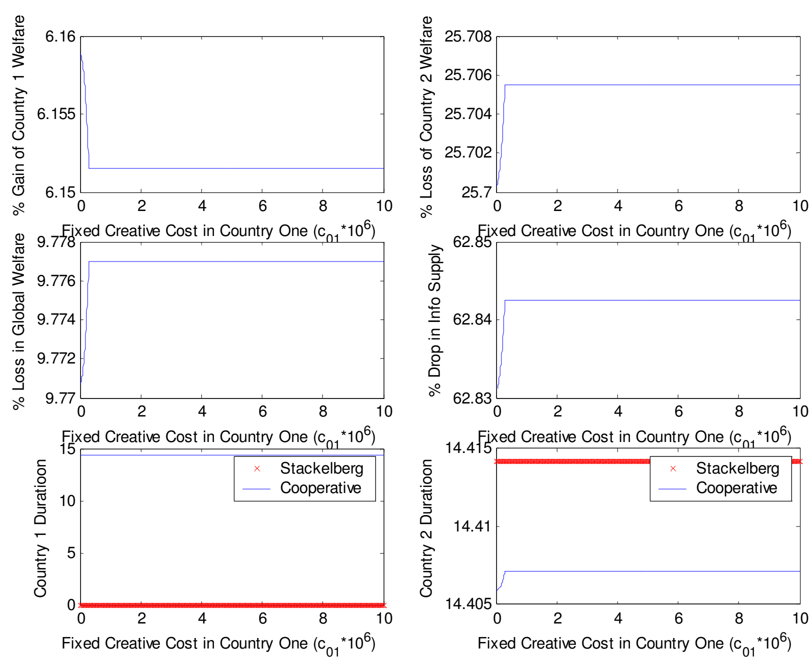


Figure 23-28: Effect of Fixed Creative Cost in Country 2

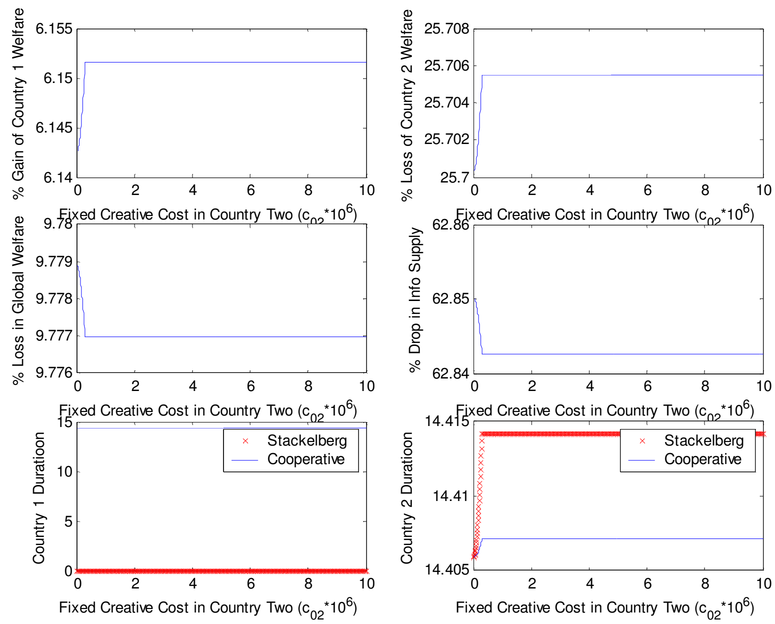
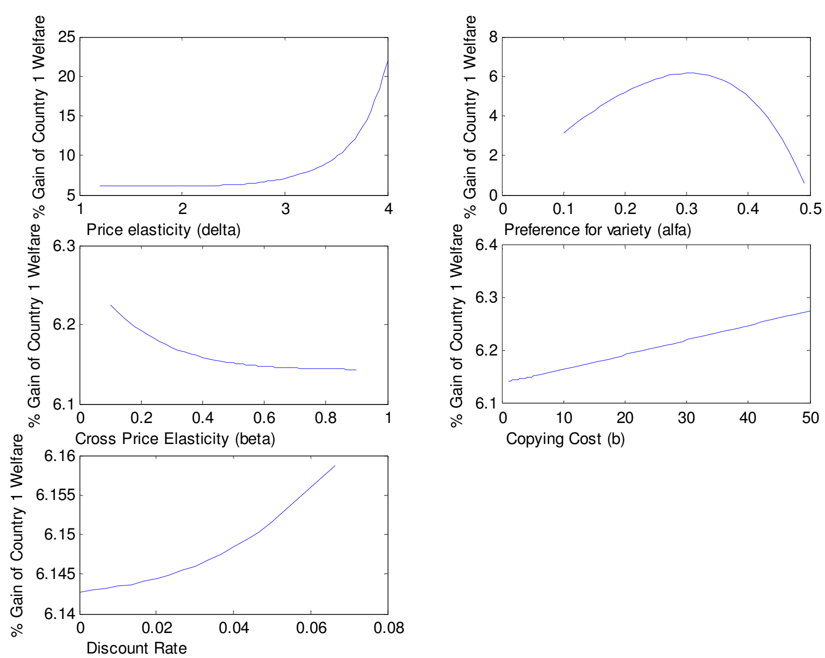


Figure 29-33: Effect of Other Parameters



Appendix: Mathematical Procedures to Solve the Stackelberg Model

The Stackelberg model can be solved numerically. The analytical procedures leading to the application of numerical method to solve the model are provided here. The procedures try first to get the same number of equations for a minimum number of variables, four in this case. Numerical method can then be applied to solve for the four variables from the four equations. Functions to calculate other market variables from the four variables are obtained.

Assuming the demand and cost functions in (11-14) and (15), one can get as in Yuan (2009):

$$p_{11i} = p_{12i} = p_{21i} = p_{22j} = p \equiv \frac{\delta}{\delta-1} b \qquad \text{(A.1)}$$

$$s_{1i} = s_{1j} \equiv s_1 \qquad \text{(A.2)}$$

$$s_{2i} = s_{2j} \equiv s_2 \qquad \text{(A.3)}$$

$$\frac{1}{s_1} + \frac{\alpha-1}{n_1 s_1 + n_2 s_2} = \frac{c_1{}'(s_1)}{c_1(s_1)} \qquad \text{(A.4)}$$

$$\frac{1}{s_2} + \frac{\alpha-1}{n_1 s_1 + n_2 s_2} = \frac{c_2{}'(s_2)}{c_2(s_2)} \qquad \text{(A.5)}$$

$$n_1 s_1 + n_2 s_2 = \frac{\alpha-1}{\frac{c_1{}'(s_1)}{c_1(s_1)} - \frac{1}{s_1}} = \frac{\alpha-1}{\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}} \qquad \text{(A.6)}$$

Then, the profit condition of the marginal creator can be rewritten as:

$$[D_1 G(T_1) + D_2 G(T_2)] s_1 \left(\frac{\alpha-1}{\frac{c_1{}'(s_1)}{c_1(s_1)} - \frac{1}{s_1}} \right)^{\alpha-1} p^{\beta-\delta}(p-b) - c_1(s_1) \le 0 \qquad \text{(A.7)}$$

$$[D_1 G(T_1) + D_2 G(T_2)] s_2 \left(\frac{\alpha-1}{\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}} \right)^{\alpha-1} p^{\beta-\delta}(p-b) - c_2(s_2) \le 0 \qquad \text{(A.8)}$$

If the profit of the marginal creator in a country is less than zero, creators of the country are out of the market. The country does not have a viable creative industry.

The consumer welfare can be re-written as:

$$cs_1 = D_1\left(\frac{\alpha-1}{\frac{c_1'(s_1)}{c_1(s_1)}-\frac{1}{s_1}}\right)^{\alpha}\frac{b^{-\delta+1}}{\delta-1}p^{\beta}G_1(\infty) - D_1\left(\frac{\alpha-1}{\frac{c_1'(s_1)}{c_1(s_1)}-\frac{1}{s_1}}\right)^{\alpha}\frac{b^{-\delta+1}-p^{-\delta+1}}{\delta-1}p^{\beta}G_1(T_1) \quad \text{(A.9)}$$

$$cs_2 = D_2\left(\frac{\alpha-1}{\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}}\right)^{\alpha}\frac{b^{-\delta+1}}{\delta-1}p^{\beta}G_2(\infty) - D_2\left(\frac{\alpha-1}{\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}}\right)^{\alpha}\frac{b^{-\delta+1}-p^{-\delta+1}}{\delta-1}p^{\beta}G_2(T_2) \quad \text{(A.10)}$$

cs_2 in (A.10) only depends on s_2 and T_2. s_2 is related to T_2 and T_1 by creators' behavior reflected in (A.8) The problem of the follower, country 2, becomes:

$$\max_{T_2} cs_2 \tag{A.11}$$

S.t. (A.8) and $T_2 \geq 0$.

Since there is a T_1 in (A.8), the solution of T_2 from (A.11) depends on T_1, which gives the reaction function of $T_2(T_1)$.

(A.8) makes s_2 an implicit function of T_2. The first order condition of (A.11) can be written as:

$$\frac{dcs_2}{dT_2} =$$

$$D_2\frac{b^{-\delta+1}}{\delta-1}p^{\beta}G_2(\infty)(\alpha-1)^{\alpha}(-\alpha)\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{-\alpha-1}\left(\frac{c_2''(s_2)c_2(s_2)-c_2'^2}{c_2^2(s_2)}+\frac{1}{s_2^2}\right)\frac{\partial s_2}{\partial T_2}$$

$$-D_2\frac{b^{-\delta+1}-p^{-\delta+1}}{\delta-1}p^{\beta}(\alpha-1)^{\alpha}(-\alpha)\left(\frac{c_2'}{c_2}-\frac{1}{s_2}\right)^{-\alpha-1}\left(\frac{c_2''c_2-c_2'^2}{c_2^2(s_2)}+\frac{1}{s_2^2}\right)\frac{\partial s_2}{\partial T_2}G_2(T_2)$$

$$-D_2\left(\frac{\alpha-1}{\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}}\right)^{\alpha}\frac{b^{-\delta+1}-p^{-\delta+1}}{\delta-1}p^{\beta}g_2(T_2)e^{-\gamma T_2} = 0 \quad \text{(A.12)}$$

The derivative $\frac{\partial s_2}{\partial T_2}$ can be obtained from (A.8) by the implicit function theorem. Taking derivative to T_2 on both sides of (A.8), one can find:

$$\frac{\partial s_2}{\partial T_2} = \frac{-[D_2 g_2(T_2)e^{-\gamma T_2}]s_2\left(\frac{c_2{}'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{1-\alpha} A}{[D_1 G_1(T_1)+D_2 G_2(T_2)]A\left[\left(\frac{c_2{}'}{c_2}-\frac{1}{s_2}\right)^{1-\alpha}+s_2(1-\alpha)\left(\frac{c_2{}'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2{}''c_2-c_2{}'^2}{c_2{}^2(s_2)}+\frac{1}{s_2{}^2}\right)\right]-c_2{}'(s_2)} \quad \text{(A.13)}$$

where

$$A \equiv p^{\beta-\delta}(p-b)(\alpha-1)^{\alpha-1} \quad \text{(A.14)}$$

cs_1 in (A.9) depends only on s_1 and T_1. s_1 is related to T_1 and T_2 by creators' behavior reflected in (A.7). And T_2 reacts to T_1 by (A.12). Thus, the problem of the leader, country 1, can be rewritten as:

$$\max_{T_1} cs_1 \quad \text{(A.15)}$$

S.t. (A.7) and (A.12) and $T_1 \geq 0$.

(A.7) makes s_1 and implicit function of T_1. The first order condition of (A.15) can be written as:

$$\frac{dcs_1}{dT_1} = D_1 \frac{b^{-\delta+1}}{\delta-1} p^\beta G_1(\infty)(\alpha-1)^\alpha(-\alpha)\left(\frac{c_1{}'(s_1)}{c_1(s_1)}-\frac{1}{s_1}\right)^{-\alpha-1}\left(\frac{c_1{}''c_1-c_1{}'^2}{c_1{}^2(s_1)}+\frac{1}{s_1{}^2}\right)\frac{\partial s_1}{\partial T_1}$$

$$-D_1\frac{b^{-\delta+1}-p^{-\delta+1}}{\delta-1}p^\beta(\alpha-1)^\alpha(-\alpha)\left(\frac{c_1{}'}{c_1}-\frac{1}{s_1}\right)^{-\alpha-1}\left(\frac{c_1{}''c_1-c_1{}'^2}{c_1{}^2(s_1)}+\frac{1}{s_1{}^2}\right)\frac{\partial s_1}{\partial T_1}G_1(T_1)$$

$$-D_1\left(\frac{\alpha-1}{\frac{c_1{}'(s_1)}{c_1(s_1)}-\frac{1}{s_1}}\right)^\alpha \frac{b^{-\delta+1}-p^{-\delta+1}}{\delta-1}p^\beta g_1(T_1)e^{-\gamma T_1} = 0 \quad \text{(A.16)}$$

The derivative $\frac{\partial s_1}{\partial T_1}$ can be obtained from (A.7) through the implicit function theorem by taking derivate to T_1 on both sides of (A.7) and noting T_2 depend on T_1 through (A.12) and (A.8):

$$[D_1 g_1(T_1) e^{-\gamma T_1}] s_1 \left(\frac{\alpha - 1}{\frac{c_1'(s_1)}{c_1(s_1)} - \frac{1}{s_1}}\right)^{\alpha - 1} p^{\beta-\delta}(p-b) +$$

$$[D_2 g_2(T_2) e^{-\gamma T_2}] s_1 \left(\frac{\alpha - 1}{\frac{c_1'(s_1)}{c_1(s_1)} - \frac{1}{s_1}}\right)^{\alpha - 1} p^{\beta-\delta}(p-b) \frac{\partial T_2}{\partial T_1} +$$

$$[D_1 G(T_1) + D_2 G(T_2)] p^{\beta-\delta}(p-b)(\alpha-1)^{\alpha-1} \times$$

$$\left[\left(\frac{c_1'(s_1)}{c_1(s_1)} - \frac{1}{s_1}\right)^{1-\alpha} + s_1(1-\alpha)\left(\frac{c_1'(s_1)}{c_1(s_1)} - \frac{1}{s_1}\right)^{-\alpha}\left(\frac{c_1''(s_1)c_1(s_1) - c_1'^2}{c_1^2(s_1)} + \frac{1}{s_1^2}\right)\right]\frac{\partial s_1}{\partial T_1}$$

$$-c_1'(s_1)\frac{\partial s_1}{\partial T_1} = 0$$

Thus,

$$\frac{\partial s_1}{\partial T_1} = \frac{-\left[D_1 g_1(T_1) e^{-\gamma T_1} + D_2 g_2(T_2) e^{-\gamma T_2} \frac{\partial T_2}{\partial T_1}\right] s_1 \left(\frac{c_1'(s_1)}{c_1(s_1)} - \frac{1}{s_1}\right)^{1-\alpha} A}{[D_1 G_1(T_1) + D_2 G_2(T_2)] A \left[\left(\frac{c_1'(s_1)}{c_1(s_1)} - \frac{1}{s_1}\right)^{1-\alpha} + s_1(1-\alpha)\left(\frac{c_1'(s_1)}{c_1(s_1)} - \frac{1}{s_1}\right)^{-\alpha}\left(\frac{c_1''c_1 - c_1'^2}{c_1^2(s_1)} + \frac{1}{s_1^2}\right)\right] - c_1'(s_1)} \quad (A.17)$$

There is the derivative $\frac{\partial T_2}{\partial T_1}$ in (A.17). Note that (A.12) and (A.8) make s_2 and T_2 implicit functions of T_1. Therefore, the term $\frac{\partial T_2}{\partial T_1}$can be obtained from (A.12) and (A.8) through the implicit function theorem by taking derivatives to T_1 on both sides of (A.12) and (A.8).

Since (A.12) contains the term $\frac{\partial s_2}{\partial T_2}$, first find $\frac{\partial^2 s_2}{\partial T_2 \partial T_1}$. From (A.13),

$$\frac{d\left(\frac{\partial s_2}{\partial T_2}\right)}{dT_1} =$$

$$\frac{-\left[D_2[g'_2(T_2) - \gamma g_2(T_2)] e^{-\gamma T_2}\right] s_2 \left(\frac{c_2'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{1-\alpha} A \frac{\partial T_2}{\partial T_1}}{[D_1 G_1 + D_2 G_2] A \left[\left(\frac{c_2'}{c_2} - \frac{1}{s_2}\right)^{1-\alpha} + s_2(1-\alpha)\left(\frac{c_2'}{c_2} - \frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2''c_2 - c_2'^2}{c_2^2(s_2)} + \frac{1}{s_2^2}\right)\right] - c_2'(s_2)}$$

$$
-\frac{[D_2 g_2(T_2)e^{-\gamma T_2}]A\left[\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{1-\alpha}+s_2(1-\alpha)\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2''c_2-c_2'^2}{c_2^2(s_2)}+\frac{1}{s_2^2}\right)\right]\frac{\partial s_2}{\partial T_1}}{[D_1G_1(T_1)+D_2G_2(T_2)]A\left[\left(\frac{c_2'}{c_2}-\frac{1}{s_2}\right)^{1-\alpha}+s_2(1-\alpha)\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2''c_2-c_2'^2}{c_2^2(s_2)}+\frac{1}{s_2^2}\right)\right]-c_2'(s_2)}
$$

$$
+\frac{[D_2 g_2(T_2)e^{-\gamma T_2}]s_2\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{1-\alpha}A}{\left\{[D_1G_1+D_2G_2]A\left[\left(\frac{c_2'}{c_2}-\frac{1}{s_2}\right)^{1-\alpha}+s_2(1-\alpha)\left(\frac{c_2'}{c_2}-\frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2''c_2-c_2'^2}{c_2^2(s_2)}+\frac{1}{s_2^2}\right)\right]-c_2'(s_2)\right\}^2}\times
$$

$$
\left\{\begin{array}{c} A\left[\left(\frac{c_2'}{c_2}-\frac{1}{s_2}\right)^{1-\alpha}+s_2(1-\alpha)\left(\frac{c_2'}{c_2}-\frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2''c_2-c_2'^2}{c_2^2}+\frac{1}{s_2^2}\right)\right]\left[D_1g_1e^{-\gamma T_1}+D_2g_2e^{-\gamma T_2}\frac{\partial T_2}{\partial T_1}\right]+ \\ \left[(D_1G_1(T_1)+D_2G_2(T_2))AH-c_2''(s_2)\right]\frac{\partial s_2}{\partial T_1} \end{array}\right\}
$$

(A.18)

where

$$
H \equiv 2(1-\alpha)\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2''c_2-c_2'^2}{c_2^2(s_2)}+\frac{1}{s_2^2}\right)
$$

$$
+(1-\alpha)(-\alpha)s_2\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{-\alpha-1}\left(\frac{c_2''c_2-c_2'^2}{c_2^2(s_2)}+\frac{1}{s_2^2}\right)^2
$$

$$
+s_2(1-\alpha)\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2'''c_2+c_2''c_2'-2c_2'c_2''}{c_2^2(s_2)}-2c_2'\frac{c_2''c_2-c_2'^2}{c_2^3(s_2)}-2\frac{1}{s_2^3}\right) \quad \text{(A.19)}
$$

Further define some terms to simplify the formulas. Let:

$$
J \equiv [D_1G_1+D_2G_2]A\left[\left(\frac{c_2'}{c_2}-\frac{1}{s_2}\right)^{1-\alpha}+s_2(1-\alpha)\left(\frac{c_2'}{c_2}-\frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2''c_2-c_2'^2}{c_2^2(s_2)}+\frac{1}{s_2^2}\right)\right]-c_2'
$$

(A.20)

$$
K \equiv \left[D_2[g'_2(T_2)-\gamma g_2(T_2)]e^{-\gamma T_2}\right]s_2\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{1-\alpha}A \quad \text{(A.21)}
$$

$$
L \equiv A\left[\left(\frac{c_2'}{c_2}-\frac{1}{s_2}\right)^{1-\alpha}+s_2(1-\alpha)\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2''c_2-c_2'^2}{c_2^2(s_2)}+\frac{1}{s_2^2}\right)\right] \quad \text{(A.22)}
$$

$$
M \equiv [D_2 g_2(T_2)e^{-\gamma T_2}]s_2\left(\frac{c_2'(s_2)}{c_2(s_2)}-\frac{1}{s_2}\right)^{1-\alpha}A \quad \text{(A.23)}
$$

Then,

$$\frac{d\left(\frac{\partial s_2}{\partial T_2}\right)}{dT_1} = \frac{-K}{J}\frac{\partial T_2}{\partial T_1} - \frac{[D_2 g_2(T_2)e^{-\gamma T_2}]\mathrm{L}}{J}\frac{\partial s_2}{\partial T_1}$$

$$+\frac{\mathrm{M}}{\mathrm{J}^2}\times\left\{L\left[D_1 g_1(T_1)e^{-\gamma T_1} + D_2 g_2(T_2)e^{-\gamma T_2}\frac{\partial T_2}{\partial T_1}\right] + [(D_1 G_1 + D_2 G_2)AH - c_2{}''] \frac{\partial s_2}{\partial T_1}\right\} \text{(A.24)}$$

or

$$\frac{d\left(\frac{\partial s_2}{\partial T_2}\right)}{dT_1} = \left\{\frac{\mathrm{M}}{\mathrm{J}^2}\times\left[\left(D_1 G_1(T_1) + D_2 G_2(T_2)\right)AH - c_2{}''(s_2)\right] - \frac{D_2 g_2(T_2)e^{-\gamma T_2}\mathrm{L}}{J}\right\}\frac{\partial s_2}{\partial T_1}$$

$$+\left[\frac{\mathrm{M}}{\mathrm{J}^2}\mathrm{L}D_2 g_2(T_2)e^{-\gamma T_2} - \frac{K}{J}\right]\frac{\partial T_2}{\partial T_1} + \frac{\mathrm{M}}{\mathrm{J}^2}\times \mathrm{L}D_1 g_1(T_1)e^{-\gamma T_1} \qquad \text{(A.25)}$$

Let:

$$U \equiv (-\alpha)\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{-\alpha-1}\left(\frac{c_2{}''(s_2)c_2(s_2) - c_2{}'^2}{c_2{}^2(s_2)} + \frac{1}{s_2{}^2}\right) \qquad \text{(A.26)}$$

$$V \equiv (-\alpha-1)\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{-\alpha-2}\left(\frac{c_2{}''c_2 - c_2{}'^2}{c_2{}^2(s_2)} + \frac{1}{s_2{}^2}\right)^2$$

$$+\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{-\alpha-1}\left(\frac{c_2{}'''c_2 + c_2{}''c_2{}' - 2c_2{}'c_2{}''}{c_2{}^2(s_2)} - 2c_2{}'\frac{c_2{}''c_2 - c_2{}'^2}{c_2{}^3(s_2)} - 2\frac{1}{s_2{}^3}\right) \text{(A.27)}$$

Now take derivative to T_1 to both sides of (A.12):

$$D_2\frac{b^{-\delta+1}}{\delta-1}p^{\beta}G_2(\infty)(\alpha-1)^{\alpha}(-\alpha)V\frac{\partial s_2}{\partial T_2}\frac{\partial s_2}{\partial T_1}$$

$$+D_2\frac{b^{-\delta+1}}{\delta-1}p^{\beta}G_2(\infty)(\alpha-1)^{\alpha}U\frac{\partial^2 s_2}{\partial T_2\partial T_1}$$

$$-D_2\frac{b^{-\delta+1}-p^{-\delta+1}}{\delta-1}p^{\beta}(\alpha-1)^{\alpha}(-\alpha)V\frac{\partial s_2}{\partial T_2}G_2(T_2)\frac{\partial s_2}{\partial T_1}$$

$$-D_2\frac{b^{-\delta+1}-p^{-\delta+1}}{\delta-1}p^{\beta}(\alpha-1)^{\alpha}(-\alpha)\left(\frac{c_2{}'}{c_2} - \frac{1}{s_2}\right)^{-\alpha-1}\left(\frac{c_2{}''c_2 - c_2{}'^2}{c_2{}^2(s_2)} + \frac{1}{s_2{}^2}\right)\frac{\partial^2 s_2}{\partial T_2\partial T_1}G_2(T_2)$$

$$-D_2 \frac{b^{-\delta+1} - p^{-\delta+1}}{\delta - 1} p^{\beta} (\alpha-1)^{\alpha} (-\alpha) \left(\frac{c_2'}{c_2} - \frac{1}{s_2}\right)^{-\alpha-1} \left(\frac{c_2'' c_2 - c_2'^2}{c_2^2(s_2)} + \frac{1}{s_2^2}\right) \frac{\partial s_2}{\partial T_2} g_2 e^{-\gamma T_2} \frac{\partial T_2}{\partial T_1}$$

$$-D_2 (\alpha-1)^{\alpha} (-\alpha) \left(\frac{c_2'}{c_2} - \frac{1}{s_2}\right)^{-\alpha-1} \left(\frac{c_2'' c_2 - c_2'^2}{c_2^2(s_2)} + \frac{1}{s_2^2}\right) \frac{b^{-\delta+1} - p^{-\delta+1}}{\delta - 1} p^{\beta} g_2 e^{-\gamma T_2} \frac{\partial s_2}{\partial T_1}$$

$$-D_2 \left(\frac{\alpha-1}{\frac{c_2'(s_2)}{c_2(s_2)} - \frac{1}{s_2}}\right)^{\alpha} \frac{b^{-\delta+1} - p^{-\delta+1}}{\delta-1} p^{\beta} \left[g'_2(T_2) - \gamma g_2(T_2)\right] e^{-\gamma T_2} \frac{\partial T_2}{\partial T_1} = 0 \qquad \text{(A.28)}$$

Further define the following terms for simplification:

$$E2 \equiv D_2 \frac{b^{-\delta+1}}{\delta-1} p^{\beta} G_2(\infty) (\alpha-1)^{\alpha} \qquad \text{(A.29)}$$

$$F2 \equiv D_2 \frac{b^{-\delta+1} - p^{-\delta+1}}{\delta-1} p^{\beta} (\alpha-1)^{\alpha} \qquad \text{(A.30)}$$

$$N \equiv D_2 \frac{b^{-\delta+1}}{\delta-1} p^{\beta} G_2(\infty) (\alpha-1)^{\alpha} (-\alpha) \left(\frac{c_2'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{-\alpha-1} \left(\frac{c_2''(s_2) c_2(s_2) - c_2'^2}{c_2^2(s_2)} + \frac{1}{s_2^2}\right) \qquad \text{(A.30)}$$

$$O \equiv D_2 \frac{b^{-\delta+1} - p^{-\delta+1}}{\delta-1} p^{\beta} (\alpha-1)^{\alpha} (-\alpha) \left(\frac{c_2'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{-\alpha-1} \left(\frac{c_2''(s_2) c_2(s_2) - c_2'^2}{c_2^2(s_2)} + \frac{1}{s_2^2}\right) \qquad \text{(A.31)}$$

$$P \equiv D_2 \left(\frac{\alpha-1}{\frac{c_2'(s_2)}{c_2(s_2)} - \frac{1}{s_2}}\right)^{\alpha} \frac{b^{-\delta+1} - p^{-\delta+1}}{\delta-1} p^{\beta} \left[g'_2(T_2) - \gamma g_2(T_2)\right] e^{-\gamma T_2} \qquad \text{(A.32)}$$

(A.28) becomes:

$$\left[E_2(-\alpha) V \frac{\partial s_2}{\partial T_2} - F_2(-\alpha) V \frac{\partial s_2}{\partial T_2} G_2(T_2) - F_2 U g_2(T_2) e^{-r T_2}\right] \frac{\partial s_2}{\partial T_1}$$

$$+[N - O G_2(T_2)] \frac{\partial^2 s_2}{\partial T_2 \partial T_1} - \left(O \frac{\partial s_2}{\partial T_2} g_2(T_2) e^{-\gamma T_2} + P\right) \frac{\partial T_2}{\partial T_1} = 0 \qquad \text{(A.33)}$$

Plug (A.25) into (A.33) for $\frac{\partial^2 s_2}{\partial T_2 \partial T_1}$, (A.33) becomes:

$$\left[\begin{array}{c} E_2(-\alpha) V \frac{\partial s_2}{\partial T_2} - F_2(-\alpha) V \frac{\partial s_2}{\partial T_2} G_2(T_2) - F_2 U g_2(T_2) e^{-r T_2} \\ +[N - O G_2(T_2)] \left(\frac{\mathrm{M}}{\mathrm{J}^2} \times \left[\left(D_1 G_1(T_1) + D_2 G_2(T_2)\right) AH - c_2''(s_2)\right] - \frac{D_2 g_2(T_2) e^{-\gamma T_2} \mathrm{L}}{J}\right) \end{array}\right] \frac{\partial s_2}{\partial T_1}$$

$$+\left[\left(N - OG_2(T_2)\right)\left[\frac{\mathrm{M}}{\mathrm{J}^2}\mathrm{L}D_2 g_2(T_2)e^{-\gamma T_2} - \frac{K}{J}\right] - \left(O\frac{\partial s_2}{\partial T_2}g_2(T_2)e^{-\gamma T_2} + P\right)\right]\frac{\partial T_2}{\partial T_1}$$

$$+[N - OG_2(T_2)]\frac{\mathrm{M}}{\mathrm{J}^2} \times \mathrm{L}D_1 g_1(T_1)e^{-\gamma T_1} = 0 \tag{A.34}$$

Further define simplifying terms:

$W \equiv$

$$\begin{bmatrix} E_2(-\alpha)V\frac{\partial s_2}{\partial T_2} - F_2(-\alpha)V\frac{\partial s_2}{\partial T_2}G_2(T_2) - F_2 U g_2(T_2)e^{-rT_2} \\ +[N - OG_2(T_2)]\left(\frac{\mathrm{M}}{\mathrm{J}^2} \times \left[\left(D_1G_1(T_1) + D_2G_2(T_2)\right)AH - c_2{}''(s_2)\right] - \frac{D_2 g_2(T_2)e^{-\gamma T_2}\mathrm{L}}{J}\right) \end{bmatrix} \tag{A.35}$$

$$R \equiv \left[\left(N - OG_2(T_2)\right)\left[\frac{\mathrm{M}}{\mathrm{J}^2}\mathrm{L}D_2 g_2(T_2)e^{-\gamma T_2} - \frac{K}{J}\right] - \left(O\frac{\partial s_2}{\partial T_2}g_2(T_2)e^{-\gamma T_2} + P\right)\right] \tag{A.36}$$

$$Q \equiv [N - OG_2(T_2)]\frac{\mathrm{M}}{\mathrm{J}^2} \times \mathrm{L}D_1 g_1(T_1)e^{-\gamma T_1} \tag{A.37}$$

(A.34) can be written as:

$$W\frac{\partial s_2}{\partial T_1} + R\frac{\partial T_2}{\partial T_1} + Q = 0 \tag{A.38}$$

Now, taking derivative to T_1 on both side of (A.8):

$$[D_1 g_1(T_1)e^{-rT_1}]s_2\left(\frac{\alpha - 1}{\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}}\right)^{\alpha-1} p^{\beta-\delta}(p - b)$$

$$+[D_2 g_2(T_2)e^{-rT_2}]s_2\left(\frac{\alpha - 1}{\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}}\right)^{\alpha-1} p^{\beta-\delta}(p - b)\frac{dT_2}{dT_1}$$

$$+\left\{[D_1G_1 + D_2G_2]A\left[\left(\frac{c_2{}'}{c_2} - \frac{1}{s_2}\right)^{1-\alpha} + (1-\alpha)s_2\left(\frac{c_2{}'}{c_2} - \frac{1}{s_2}\right)^{-\alpha}\left(\frac{c_2{}''c_2 - c_2{}'^2}{c_2{}^2(s_2)} + \frac{1}{s_2{}^2}\right)\right] - c_2{}'\right\}\frac{ds_2}{dT_1} = 0 \tag{A.39}$$

Thus,

$$\frac{ds_2}{dT_1} = -\frac{[D_2 g_2(T_2)e^{-rT_2}]s_2\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{1-\alpha} A}{J}\frac{dT_2}{dT_1}$$

$$-\frac{[D_1 g_1(T_1)e^{-rT_1}]s_2\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{1-\alpha} A}{J} \tag{A.40}$$

Plus (A.40) into (A.28),

$$\left\{R - W\frac{[D_2 g_2(T_2)e^{-rT_2}]s_2\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{1-\alpha} A}{J}\right\}\frac{dT_2}{dT_1}$$

$$+Q - W\frac{[D_1 g_1(T_1)e^{-rT_1}]s_2\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{1-\alpha} A}{J} = 0$$

We have:

$$\frac{dT_2}{dT_1} = -\frac{Q - W\frac{[D_1 g_1(T_1)e^{-rT_1}]s_2\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{1-\alpha} A}{J}}{R - W\frac{[D_2 g_2(T_2)e^{-rT_2}]s_2\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{1-\alpha} A}{J}} \tag{A.41}$$

Now, collect the equations,

$$f_1 = [D_1 G(T_1) + D_2 G(T_2)]s_1\left(\frac{\alpha-1}{\frac{c_1{}'(s_1)}{c_1(s_1)} - \frac{1}{s_1}}\right)^{\alpha-1} p^{\beta-\delta}(p-b) - c_1(s_1) = 0 \tag{A.42}$$

$$f_2 = [D_1 G(T_1) + D_2 G(T_2)]s_2\left(\frac{\alpha-1}{\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}}\right)^{\alpha-1} p^{\beta-\delta}(p-b) - c_2(s_2) = 0 \tag{A.43}$$

$$f_3 = D_2\frac{b^{-\delta+1}}{\delta-1}p^{\beta}G_2(\infty)(\alpha-1)^{\alpha}(-\alpha)\left(\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}\right)^{-\alpha-1}\left(\frac{c_2{}''c_2 - c_2{}'^2}{c_2{}^2(s_2)} + \frac{1}{s_2{}^2}\right)\frac{\partial s_2}{\partial T_2}$$

$$-D_2\frac{b^{-\delta+1} - p^{-\delta+1}}{\delta-1}p^{\beta}(\alpha-1)^{\alpha}(-\alpha)\left(\frac{c_2{}'}{c_2} - \frac{1}{s_2}\right)^{-\alpha-1}\left(\frac{c_2{}''c_2 - c_2{}'^2}{c_2{}^2(s_2)} + \frac{1}{s_2{}^2}\right)\frac{\partial s_2}{\partial T_2}G_2(T_2)$$

$$-D_2\left(\frac{\alpha-1}{\frac{c_2{}'(s_2)}{c_2(s_2)} - \frac{1}{s_2}}\right)^{\alpha}\frac{b^{-\delta+1} - p^{-\delta+1}}{\delta-1}p^{\beta}g_2(T_2)e^{-\gamma T_2} = 0 \tag{A.44}$$

$$f_4 = D_1 \frac{b^{-\delta+1}}{\delta - 1} p^{\beta} G_1(\infty)(\alpha - 1)^{\alpha}(-\alpha)\left(\frac{c_1{}'(s_1)}{c_1(s_1)} - \frac{1}{s_1}\right)^{-\alpha-1}\left(\frac{c_1{}''c_1 - c_1{}'^2}{c_1{}^2(s_1)} + \frac{1}{s_1{}^2}\right)\frac{\partial s_1}{\partial T_1}$$

$$-D_1 \frac{b^{-\delta+1} - p^{-\delta+1}}{\delta - 1} p^{\beta}(\alpha - 1)^{\alpha}(-\alpha)\left(\frac{c_1{}'}{c_1} - \frac{1}{s_1}\right)^{-\alpha-1}\left(\frac{c_1{}''c_1 - c_1{}'^2}{c_1{}^2(s_1)} + \frac{1}{s_1{}^2}\right)\frac{\partial s_1}{\partial T_1} G_1(T_1)$$

$$-D_1\left(\frac{\alpha-1}{\frac{c_1{}'(s_1)}{c_1(s_1)} - \frac{1}{s_1}}\right)^{\alpha} \frac{b^{-\delta+1} - p^{-\delta+1}}{\delta-1} p^{\beta} g_1(T_1) e^{-\gamma T_1} = 0 \qquad \text{(A.45)}$$

where $\frac{\partial s_1}{\partial T_1}$ and $\frac{\partial s_2}{\partial T_2}$ are functions of T_1, T_2, s_1, s_2 by (A.17) and (A.13), respectively. Therefore, f_1, f_2, f_3, and f_4 are only functions of s_1, s_2, T_1, and T_2. The four variables, s_1, s_2, T_1, and T_2, can be solved from the four equations by numerical method, given parameter values in the demand and cost functions. Then, the total number of first-copy products, S, and social welfare of country 1 and country 2, cs_1 and cs_2, can be easily obtained from (A.6), (A.9) and (A.10).