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International Labor Standards and Their Harmonization

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Abstract This paper studies the economic aspects of international labor standards (LS) in a North-South framework. We consider three regimes of LS: free choices, a policy game between two governments, and international harmonization. In the absence of trade restrictions, the North has a higher LS due to a lower wage-technology ratio, or a lack of market competition. Contrary to conventional wisdom, a simple import tariff decreases the Southern LS, because it reduces the Southern output which lowers the Southern incentives to invest in LS. On the other hand, a LS-specific tariff can raise the Southern LS. Under the policy game, the South can produce a higher or lower LS than under free choices of LS, depending on the level of the Northern import tariff. International harmonization under a uniform, minimum LS binding for both countries lowers Northern profits and welfare. It is also shown that both countries can obtain higher profits and welfare through technology transfer at a positive reimbursement, without intervention by governments or international organizations.

Keywords: Labor Standards, International Harmonization, Technology Transfer, Oligopoly, Policy Game, Trade Restrictions

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1. Introduction

The issue of labor standards (LS) has generated heated debates recently. An example is during the WTO meeting of finance ministers in November 1999, thousands of demonstrators succeeded in bringing their talks to a halt in Seattle. Such groups demand that the WTO address international LS along with trade issues, and claim that market access in the North should be conditioned on raising LS in the South, to prevent “social dumping” or a "race to the bottom" in wages and benefits. They ask that since the WTO already addresses issues such as the protection of intellectual property rights that fall outside of a strict definition of trade and investment, why it cannot also act to protect the interests of workers by setting LS. Some even advocate a “social clause” that trade sanctions be imposed in response to violations of LS.

This point of view presumes that workers benefit from LS protection, which is novel but has not been analyzed formally in economic theory. Some economists argue that LS adds to consumer utility (Rodrik, 1996), or national welfare (Brown, Deardorff and Stern, 1995; Srinivasan, 1995). However, in these analyses, workers and firms do not benefit directly from a higher LS. On the other hand, firms must bear the cost of producing it. Thus it is no wonder that firms have no incentives to improve LS. Furthermore, an average consumer simply does not have enough information to tell whether a product is made with high or low LS, especially when it is imported from a foreign country.

The Core Labor Standards promoted by the International Labor Organization (ILO) cover very broad contents, including for instance freedom of communication and unionization, nondiscrimination, no child labor, no forced labor, etc. In this paper, we are interested in modeling only the economic aspects of LS.In our view, while it is costly to maintain a certain level of LS, a higher LS also improves labor productivity and benefits workers. In fact, Hunter (2003) documents that the enforcement of the Japanese Factory Act (enacted in 1911) reduced labor hours and prohibited midnight work in Japan. Subsequently, in the textile industry where women were the main workforce, the health condition of workers improved and their productivity increased. In turn, product quality rose (pp202-204). It seems that weak labor standards in developing countries, like low wages, are a consequence of low productivity and poverty, not an independent source of international comparative advantage.

With the above in mind, we specifically consider LS to exhibit in three forms. One is work safety, ventilation, clean and comfortable work environment, etc., which is not embodied in the worker physically; the second is health improvement, which is embodied in the worker; the third is a reduction of child labor (i.e., replacement with adult labor) or an increase in the minimum wage, which can raise productivity indirectly. In addition, the home government's utility can increase if foreign LS (or human rights) rises. These features of LS distinguish themselves from human capital or R&D investments.

If one agrees that LS benefits workers and contributes to worker productivity, then it is not hard to see that even in poor countries, maintaining a certain level of LS is beneficial to workers, firms and national welfare there, because the productivity increase with a higher LS brings a higher marginal revenue, leading the firm to hire more workers and produce more output. This paper thus assumes a North-South, two-firm framework, with consumption only in the more developed North which has a lower wage-technology ratio. The Northern government also imposes an import tariff which has a "simple" part and a "LS-specific" part, hoping to raise foreign LS. Firms compete à la Cournot, choosing how much final output to produce.

We consider three regimes: free choices of LS by firms, a policy game between two governments, and international harmonization of LS. Firms, governments or the international organization optimize to choose their respective levels of LS. In the absence of trade restrictions, the South implements a lower LS due to a higher wage-technology ratio. That is, even though LS contributes to productivity, the Southern firm does not implement the Northern firm's level of LS.

Contrary to conventional wisdom, the "simple" part of the import tariff, which is aimed at forcing up the Southern LS unconditionally, is not effective, because it reduces the Southern output which lowers the Southern incentives to invest in LS. On the other hand, the "LS-specific" part, which would lower the tariff if Southern LS rises, can effectively raise the Southern LS. Thus, the simple tariff can be called a stick policy, while the LS-specific tariff a carrot policy.

Under the policy game between governments, two cases arise: (i). Near the neighborhood of free trade, the North produces a higher LS than under free choices of LS, because the government maximizes national welfare including consumer surplus, which requires the North to expand output and invest more in LS. As a consequence, the South's market share is squeezed out and its LS forced to fall; (ii). If the import tariff is sufficiently high which causes too much deviation from free trade, the effects on tariff revenue can dominate those on consumer surplus, then the Northern government may choose a lower LS than the Northern firm. And the opposite is true in the South.

Under international harmonization, a world welfare maximizing uniform LS is only binding for the South but not for the North, because the North voluntarily chooses a higher one due to its lower wage-technology ratio. On the other hand, a common, minimum LS binding for both countries does exist, but it will lower the profits and welfare of the North. A more efficient alternative is technology transfer at a positive reimbursement. It is shown that the world welfare maximizing equilibrium can be restored, without any interventions from the governments or international organizations.

In the existing literature, Bhagwati (1995) and Basu (1999) believe that the recent surge in the demands for LS stems overwhelmingly from lobbies whose true agenda is protectionism. Srinivasan (1995) and Brown, Deardorff and Stern (1996) and Brown (2001) demonstrate that the diversity of LS between nations reflect differences in factor endowments and levels of income. Martin and Maskus (2001) show that a failure to establish and enforce LS may reduce an economy's efficiency and interferes with its comparative advantage. Bagwell and Staiger (2001) argue that efficiency can be achieved without negotiating over LS. Different from these papers which are mostly in general equilibrium with perfect competition, we analyze the problem under oligopoly, explicitly incorporating LS that contributes to production. We also adopt an import tariff that can act as both a "stick" and a "carrot".

The remainder of the paper is organized as follows. Section 2 sets up the basic model. Section 3 examines the regime of free choices of LS. Section 4 looks into the policy game between governments. Section 5 introduces international harmonization. Section 6 considers different LS allowed for the two countries under world welfare maximization. Section 7 investigates technology transfer. And section 8 concludes.

2. Basic Model Setup

Consider two firms N and S producing an identical product in two different countries the North and the South respectively. Denote each firm's output $Y_i, \quad i = \text{N, S}$. Production requires input labor only, in the following manner:

$$L_i = f(\theta_i)Y_i / a_i . \tag{1}$$

That is, to produce Y_i units of the final output, L_i units of labor are required. In (1), a_i is a technology parameter, θ_i denotes firm i's LS, which reduces the amount of labor input required for production such that $f' < 0,\ \ f'' > 0$. Alternatively, $\frac{\partial^2 Y_i}{\partial L_i \partial \theta_i} = -\frac{a_i f'}{f^2(\theta)} > 0$. That is, an increase in LS raises the marginal product of labor in producing the final output. This aspect of LS is similar to how R&D or human capital investment affects production. But we focus on international harmonization of LS, its impact on national and world welfare, and the effects of the import tariff. There is no market for LS hence each firm must produce it by itself.

We assume that final outputs are only sold in the North, and the Northern government imposes a tariff on imports. Using (1), the profit functions of both firms can be written as

$$\pi_i(Y_N, Y_S, \theta_i; t_j, c_i, a_i, w_i) \equiv pY_i - w_i L_i - c_i\theta_i - t_j Y_i = \{p - r_i f(\theta_i) - t_j\}Y_i - c_i\theta_i, \ \ t_S = 0 \tag{2}$$

where $p = p(Y_N + Y_S)$ is the inverse demand, with $p' < 0$, c_i is the unit cost of producing LS,[1] t_j is an import tariff imposed by country $j \neq i$, w_i is the wage rate, and $r_i \equiv w_i / a_i$, which can be interpreted as the wage-technology ratio. This setup includes two sides of LS: it is costly to produce LS; and also, a higher LS reduces the unit cost of final production Y_i. These two effects work against each other. The parameters c_i and a_i measure respectively the technologies in producing LS and in using it to produce the final output.

In the literature, it is commonly assumed that the Northern government cares about Southern LS, but the modeling approach has been to include Southern LS in the Northern welfare function directly. In the present paper, we model it a little differently. To induce a higher LS from the South, the Northern government imposes an import tariff, according to the following rule:

$$t_N = \tau_0 + \tau_1(\underline{\theta} - \theta_S), \qquad (3)$$

where τ_0 and τ_1 are imposed at the beginning by the Northern government. There is a "reservation tariff" of $\tau_0 \geq 0$. And variable τ_1 captures the Northern government's valuation of Southern LS. A higher τ_1 implies that the Northern government cares more about Southern LS, and is willing to reduce the import tariff if the Southern LS θ_S is above a given reservation level $\underline{\theta}$. And if θ_S falls short of $\underline{\theta}$, then the import tariff increases by a factor τ_1. In other words, τ_0 is a simple tariff that acts as a stick in the usual sense, as advocated by activists of a "social clause," while τ_1 is a LS-specific tariff that acts as a carrot.

We consider a two-stage game. At an initial state, the Northern government already imposed the import tariff, i.e., determining τ_0 and τ_1. Then in the first stage, LS is chosen in each country.

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[1] Using an increasing marginal cost instead of a unit cost (constant marginal cost) does not change the qualitative results of the model, as long as the second order conditions for profit maximization are satisfied.

There are three regimes separately: free choices of LS by firms, a policy game of LS between governments, and international harmonization of LS. In each regime, given the tariffs, LS is chosen either freely by firms simultaneously, or by governments simultaneously, or internationally harmonized by an international organization such as the International Labor Organization (ILO). The assumption that the tariff is imposed prior to the determination of LS reflects our wish to examine the impact of a Northern tariff on Southern LS. Finally in the second stage, the two firms compete à la Cournot -- choosing outputs simultaneously. The game is solved backwards to ensure consistency.

In all three regimes, the second stage is Cournot competition in output. The first order conditions (FOCs) for the Northern and Southern firms are respectively:

$$p + Y_N p' - f(\theta_N) r_N = 0, \tag{4a}$$

$$p + Y_S p' - f(\theta_S) r_S - t_N = 0. \tag{4b}$$

Eqs (4a) and (4b) determine the equilibrium output of firm i, $Y_i(\cdot) \equiv Y_i(\theta_N, \theta_S; t_N, r_N, r_S)$.

To simplify notation, let $f(\theta_i) \equiv f_i$, $f'(\theta_i) \equiv f_i^{'}$, $f''(\theta_i) \equiv f_i^{''}$. Then using (2), total differentiation of (4a) and (4b) yields

$$\begin{pmatrix} 2p' + Y_N p'' & p' + Y_N p'' \\ p' + Y_S p'' & 2p' + Y_S p'' \end{pmatrix} \begin{pmatrix} dY_N \\ dY_S \end{pmatrix} = \begin{pmatrix} r_N f_N^{'} \\ 0 \end{pmatrix} d\theta_N + \begin{pmatrix} 0 \\ r_S f_S^{'} - \tau_1 \end{pmatrix} d\theta_S$$
$$+ \begin{pmatrix} f_N \\ 0 \end{pmatrix} dr_N + \begin{pmatrix} 0 \\ f_S \end{pmatrix} dr_S + \begin{pmatrix} 0 \\ 1 \end{pmatrix} dt_N$$

where $\Delta = \begin{pmatrix} 2p' + Y_N p'' & p' + Y_N p'' \\ p' + Y_S p'' & 2p' + Y_S p'' \end{pmatrix} = 3(p')^2 + (Y_N + Y_s) p' p'' > 0$. From the above we obtain the following comparative static results, for $i, j = N, S, \;\; i \neq j$.

$$\frac{\partial Y_N(\cdot)}{\partial \theta_N} = r_N f_N^{'} (2p' + Y_S p'') / \Delta > 0 , \tag{5a}$$

$$\frac{\partial Y_S(\cdot)}{\partial \theta_N} = -r_N f_N^{'} (p' + Y_S p'') / \Delta < 0 , \tag{5b}$$

$$\frac{\partial Y_S(\cdot)}{\partial \theta_S} = (2p' + Y_N p'')[r_S f_S^{'} - \tau_1] / \Delta > 0 , \tag{5c}$$

$$\frac{\partial Y_N(\cdot)}{\partial \theta_S} = -(p' + Y_N p'')[r_S f_S^{'} - \tau_1] / \Delta < 0 , \tag{5d}$$

$$\frac{\partial Y_i(\cdot)}{\partial r_j} = -(p' + Y_i p'') f_j / \Delta > 0 , \tag{5e}$$

$$\frac{\partial Y_i(\cdot)}{\partial r_i} = (2p' + Y_i p'') f_i / \Delta < 0 , \tag{5f}$$

$$\frac{\partial Y_N(\cdot)}{\partial \tau_0} = \frac{\partial Y_N(\cdot)}{\partial t_N} = -(p' + Y_N p'') / \Delta > 0 , \tag{5g}$$

$$\frac{\partial Y_S(\cdot)}{\partial \tau_0} = \frac{\partial Y_S(\cdot)}{\partial t_N} = (2p' + Y_N p'') / \Delta < 0 , \tag{5h}$$

$$\frac{\partial Y_N(\cdot)}{\partial \tau_1} = (\underline{\theta} - \theta_S) \frac{\partial Y_N(\cdot)}{\partial \tau_0} > 0 , \quad \text{if } \underline{\theta} > \theta_S , \tag{5i}$$

$$\frac{\partial Y_S(\cdot)}{\partial \tau_1} = (\underline{\theta} - \theta_S) \frac{\partial Y_S(\cdot)}{\partial \tau_0} < 0 , \quad \text{if } \underline{\theta} > \theta_S . \tag{5j}$$

Condition (5a) captures the impacts of θ_N on Y_N. An increase in θ_N reduces the labor requirement in final production through $f(\theta_N)$, which in turn raises Y_N. Condition (5b) indicates the impacts of θ_N on Y_S, which is just the opposite of (5a). Conditions (5c) and (5d) show the effects of θ_S on Y_N and Y_S, which are qualitatively similar to (5a) and (5b). Note that due to the tariff rule in (3), LS in the two countries affect outputs asymmetrically.

From (5e) and (5f), an increase in own wage-technology ratio reduces own but raises the rival's output. Conditions (5g) and (5h) are as expected, stating that an increase in the import tariff (or reservation tariff) raises the Northern output but reduces the Southern one. And finally conditions (5i) and (5j) are qualitatively similar, provided that $\underline{\theta} > \theta_S$.

So far we have solved for the final output of firm i, which can be written as a function of LS in both countries and the import tariff. We now move on backwards to stage one, in which there are three different regimes.

3. Free Choice of Labor Standards

In this section we examine the regime in which firms can decide LS by themselves. Subsequent sections will deal with regimes of LS determined by governments or international organizations. Define the first-stage profit functions by substituting $Y_i(\cdot) \equiv Y_i(\theta_N, \theta_S; t_N, r_N, r_S)$ into (2),

$$\tilde{\pi}_i(\theta_N, \theta_S; t_N, v) \equiv \{p(\cdot) - r_i f(\theta_i) - t_j\} Y_i(\cdot) - c_i \theta_i , \qquad (6)$$

where $v \equiv (c_N, c_S, r_N, r_S)$ is the vector of parameters, and $p(\cdot) = p(Y_N(\cdot) + Y_S(\cdot))$. Under free choice of LS, each firm chooses its own LS θ_i to maximize profits. Using the envelope theorem, the first order conditions can be obtained as:

$$\frac{\partial \tilde{\pi}_N}{\partial \theta_N} = \frac{\partial \pi_N}{\partial Y_S} \frac{\partial Y_S}{\partial \theta_N} - c_N - f_N^{'} r_N Y_N = 0 , \qquad (7a)$$

$$\frac{\partial \tilde{\pi}_S}{\partial \theta_S} = \frac{\partial \pi_S}{\partial Y_N} \frac{\partial Y_N}{\partial \theta_S} - c_S - f_S^{'} r_S Y_S + \tau_1 Y_S = 0 , \qquad (7b)$$

where $\frac{\partial \pi_j}{\partial Y_i} = Y_j p'$.

The first terms in (7a) and (7b) capture the strategic effects of LS: raising own LS reduces the rival's output, which in turn benefits the firm itself. The strategic effect induces firms to invest more on LS. The second terms indicate the cost of producing LS, and the third terms represent the effect that increasing LS reduces the unit cost of final production. In (7b), there is a forth term $\tau_1 Y_S$, which stems from (3); that is, an increase in θ_S reduces the tariff for any given $\underline{\theta}$, which in turn raises Y_S.

Next, we investigate the properties of the Nash equilibrium determined by (7a) and (7b). Due to the two-stage game structure of the model, further comparisons involve the differentiation of *p"*, resulting in *p"'*, which is hard to interpret as far as economic intuition is concerned. We therefore assume $p''=0$ so that the demand curve becomes linear. Then conditions (7a) and (7b) can be simplified to

$$A_N(\theta_N,\theta_S;v) \equiv -\frac{4}{3} r_N f_N^{'} Y_N - c_N = 0, \qquad \text{(7a')}$$

$$A_S(\theta_N,\theta_S;v) \equiv \frac{4}{3}(\tau_1 - r_S f_S^{'}) Y_S - c_S = 0. \qquad \text{(7b')}$$

Note that in the literature, LS does not benefit workers or firms such that $f(\theta_i)=0$. From the above two equations it is obvious that a race to the bottom in LS would arise. In the present model, due to (1) and the properties of $f(\theta_i)$, firms choose the optimal level of LS to maximize profits. Hence a race to the bottom of LS does not arise in general.

They yield the best response functions

$$\theta_N = \theta_N(\theta_S; r_N, r_S, c_N, \tau_0, \tau_1, \underline{\theta}), \qquad \text{(7a")}$$

$$\theta_S = \theta_S(\theta_N; r_N, r_S, c_S, \tau_0, \tau_1, \underline{\theta}), \qquad \text{(7b")}$$

which determine the Nash equilibrium levels of LS . These functions can be plotted as in Figure 1, in which θ_S and θ_N are on the horizontal and vertical axes respectively. Calculations in the Appendix give the slopes of the best response functions as

$$\left.\frac{d\theta_N}{d\theta_S}\right|_N = -\frac{\partial A_N / \partial\theta_S}{\partial A_N / \partial\theta_N} = -\frac{r_N f_N^{'} \partial Y_N / \partial\theta_S}{r_N f_N^{'} \partial Y_N / \partial\theta_N + r_N Y_N f_N^{''}} < 0, \quad (8a)$$

$$\left.\frac{d\theta_N}{d\theta_S}\right|_S = -\frac{\partial A_S / \partial\theta_S}{\partial A_S / \partial\theta_N} = -\frac{(\tau_1 - r_S f_S^{'})\partial Y_S / \partial\theta_S - r_S Y_S f_S^{''}}{(\tau_1 - r_S f_S^{'})\partial Y_S / \partial\theta_N} < 0. \quad (8b)$$

Further, we have $\left.\frac{d\theta_N}{d\theta_S}\right|_{\mathrm{N}} - \left.\frac{d\theta_N}{d\theta_S}\right|_{\mathrm{S}} = \left(\frac{\partial A_N}{\partial\theta_N}\right)^{-1}\left(\frac{\partial A_S}{\partial\theta_N}\right)^{-1} D > 0$, which leads to

$$0 > \left.\frac{d\theta_N}{d\theta_S}\right|_{\mathrm{N}} > \left.\frac{d\theta_N}{d\theta_S}\right|_{\mathrm{S}}. \quad (9)$$

Thus, both best response functions in LS space are negatively sloped,[2] but (7a") is flatter. Let us start at $\tau_0 = \tau_1 = 0,\ r_S = r_N$, and $c_S = c_N$, then the best response curves intersect at point H. Further, if we fix c_N at the level of point H, but increase c_S only, then South's best response curve shifts downward, resulting in a new intersection point F in Figure 1, with a lower LS in the South and a higher one in the North.

Now, totally differentiating (7a) and (7b) we also derive respectively the full impacts of the wage-technology ratio (see the Appendix for details). Again, start at a situation where $\tau_0 = \tau_1 = 0,\ r_S = r_N$, and $c_S = c_N$. Then, slightly increasing r_N, we obtain

$$\frac{d(\theta_N - \theta_S)}{dr_N} = \frac{16B}{9D}\left\{\frac{r_i f_i f_i^{'}}{p'}\right\}(\mu - 1)\,, \qquad (10)$$

where $B = \left[r_i Y_i f_i^{"} + \frac{(r_i f_i^{'})^2}{3p'} \right] > 0$ by the second order conditions, and $\mu \equiv \frac{p - r_i f_i}{r_i f_i}$. Since $r_i f_i$ is the marginal cost in the second stage Cournot output game (see (4a) and (4b)), μ is the mark-up ratio, or the unit markup above marginal cost. Thus,

Proposition 1: *(i). Suppose that the initial equilibrium is completely symmetric. An increase in the wage-technology ratio of the North raises (reduces) the Northern LS relative to the Southern one if* $\mu >$ $(<)\ 1$. *(ii). A higher cost of producing LS results in a lower level of LS.*

Since the Northern wage rate is usually believed to be higher than the Southern one, it is difficult to explain why firms in the North willingly adopt higher LS than those in the South, except by labor laws or government regulation. However, Proposition 1 implies that there are at least a couple of reasons for the Northern LS to be higher than the Southern one, in the absence of any government intervention. One is technology, more specifically, the cost of creating LS c_i and the wage-technology ratio r_i. Obviously a higher cost results in a lower LS. Moreover, the North can adopt a higher LS because its wage-technology ratio may be lower. In other words, though the Northern wage rate is higher, its technology is even better, resulting in a lower wage-technology ratio.

The other is market competitiveness. From (7a'), an increase in the wage-technology ratio has three effects, on r_N, $f_N^{'}$ and Y_N respectively. Intuitively, if r_N rises, the firm must pay a higher wage cost for final production, which induces the firm to produce a higher LS to improve

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[2] As long as LS contributes to production, we obtain negatively sloped best response curves in LS space even under slightly different setups, such as price competition in final outputs, or with constant elasticity of substitution demand functions.

productivity so that few workers can be hired. In other words, the savings from wage costs are higher under a higher wage-technology ratio. In addition, if $\mu > 1$, markets are not so competitive. The firm can markup price to more than offset the increase in the marginal cost. Then, an increase in the wage-technology ratio would raise the price proportionally more than the marginal cost, leading the firm to produce a higher Y_N. In this case, even though the wage-technology ration is higher in the North than in the South, the LS is higher in the former country too.

Next, an increase in the Northern reservation tariff, $d\tau_0 \ (= dt_N > 0)$, has the following effects:

$$D\frac{d\theta_N}{dt_N} = -\{\frac{\partial A_N}{\partial t_N}\frac{\partial A_S}{\partial \theta_S} - \frac{\partial A_S}{\partial t_N}\frac{\partial A_N}{\partial \theta_S}\} > 0, \tag{11a}$$

$$D\frac{d\theta_S}{dt_N} = -\{\frac{\partial A_S}{\partial t_N}\frac{\partial A_N}{\partial \theta_N} - \frac{\partial A_N}{\partial t_N}\frac{\partial A_S}{\partial \theta_N}\} < 0, \tag{11b}$$

where detailed calculations are contained in the Appendix. Thus,

Proposition 2: *An increase in the Northern reservation tariff raises (reduces) the Northern (Southern) LS.*

Proposition 2 runs counter to the expectations of those who advocate imposing trade restrictions against countries observing lower LS. They hoped to use trade restrictions to force Southern countries to adopt a higher LS. However, Proposition 2 says that the opposite may arise. The intuition is, an increase in Northern tariff reduces South’s output, driving up the market price. This in turn raises North’s marginal revenue and output, enabling it to invest more on upgrading LS to reduce the unit cost. On the other hand, the opposite arises in the South. That is, since LS is costly to obtain, and the Northern import tariff reduces the South's exports, the Southern firm is forced to produce a lower LS. These can be confirmed in Figure 1. An increase in the tariff under free choices of LS would shift up the Northern best response curve, but does the opposite to the Southern one, moving their intersection to the northwest (not drawn).

Proposition 2 can also shed light on human rights concerns in the sense that the Northern consumers and government care about Southern LS, as claimed by Northern humanitarian groups, labor unions and NGOs. Suppose Southern LS enters positively the utility function of Northern consumers given in (13a) below, such that the North is better off with a higher Southern LS. Then by Proposition 2, an increase in the import tariff reduces Southern LS, which in turn lowers Northern welfare. Therefore, it is better not to impose the tariff to force the South to adopt a higher LS.

Finally we look into the effects of the Northern government's valuation of Southern LS. We consider the following tariff scheme: suppose that we increase τ_1 but keep the overall tariff t_N unchanged by decreasing the reservation tariff, given the same level of θ_S. Then we must have $d\tau_1 > 0$ and $d\tau_0 + (\underline{\theta} - \theta_S)d\tau_1 = 0$. Using these and the Appendix to obtain

$$\begin{pmatrix} \frac{\partial A_N}{\partial \theta_N} & \frac{\partial A_N}{\partial \theta_S} \\ \frac{\partial A_S}{\partial \theta_N} & \frac{\partial A_S}{\partial \theta_S} \end{pmatrix} \begin{pmatrix} d\theta_N \\ d\theta_S \end{pmatrix} = (\underline{\theta} - \theta_S) \begin{pmatrix} \frac{\partial A_N}{\partial \tau_0} \\ \frac{\partial A_S}{\partial \tau_0} \end{pmatrix} d\tau_1 - \begin{pmatrix} \frac{\partial A_N}{\partial \tau_1} \\ \frac{\partial A_S}{\partial \tau_1} \end{pmatrix} d\tau_1 = -\begin{pmatrix} 0 \\ \frac{4}{3} Y_S \end{pmatrix} d\tau_1 ,$$

which leads to

$$\frac{d\theta_N}{d\tau_1} = \frac{4}{3} Y_S \frac{\partial A_N}{\partial \theta_S} / D < 0 , \tag{12a}$$

$$\frac{d\theta_S}{d\tau_1} = -\frac{4}{3} Y_S \frac{\partial A_N}{\partial \theta_N} / D > 0 . \tag{12b}$$

Therefore we can establish:

Proposition 3: *The Southern LS can be raised by increasing the incentive tariff* τ_1 *but keep the overall tariff* t_N *unchanged by decreasing the reservation tariff, given the same level of* θ_S .

It is interesting to compare Propositions 2 and 3. While the former states that the "stick" in the form of a simple, ordinary import tariff does not work, the latter says that the "carrot" is effective, by providing incentives to the South to raise its LS. Thus, it is important for the Northern government to adopt a tariff structure that is more dependent on Southern LS.

4. A Policy Game of Labor Standards

In this section, we investigate the case in which the governments in the two countries play a policy game, choosing own LS to maximize national welfare, which is the difference with the previous section. The LS chosen by the governments may be different from those chosen by the firms. We compare them and analyze the impacts on profits and welfare.

The game still has two stages. Everything stays the same as in the previous section except that in stage one, here the governments choose LS simultaneously to maximize own national welfare. Then in stage two, when firms compete à la Cournot -- choosing outputs simultaneously, conditions (5a) to (5j) still hold valid.

Using (7a') and (7b'), the Northern welfare can be written as

$$\psi_N(\theta_N, \theta_S; v) = \tilde{\pi}_N(\theta_N, \theta_S; v) + \phi(\theta_N, \theta_S; v) + R(\theta_N, \theta_S; v), \qquad (13a)$$

where $R(\theta_N, \theta_S; v) = t_N Y_S(\theta_N, \theta_S; v)$ is the tariff revenue. On the other hand, the Southern welfare consists of profits only because all outputs are exported,

$$\psi_S(\theta_N,\theta_S;v)=\tilde{\pi}_S(\theta_N,\theta_S;v)\,. \tag{13b}$$

In stage one, the governments choose θ_N and θ_S simultaneously to maximize (13a) and (13b) respectively, resulting in the following FOCs,

$$\frac{\partial\psi_N(\theta_N,\theta_S;v)}{\partial\theta_N}=\frac{\partial\tilde{\pi}_N}{\partial\theta_N}+\frac{\partial\phi}{\partial\theta_N}+\frac{\partial R}{\partial\theta_N}=0\,, \tag{14a}$$

$$\frac{\partial\psi_S(\theta_N,\theta_S;v)}{\partial\theta_S}=\frac{\partial\tilde{\pi}_S}{\partial\theta_S}=0\,. \tag{14b}$$

In (14a), the first term on the RHS is the effects on profits, the second and third terms are respectively the effects on consumer surplus and the tariff revenue. On consumer surplus,

$$\frac{\partial\phi}{\partial\theta_N}=-(Y_N+Y_S)p'\frac{\partial(Y_N+Y_S)}{\partial\theta_N}=-\frac{1}{3}(Y_N+Y_S)r_N f_N^{'}>0\,. \tag{15}$$

An increase in Northern LS θ_N raises Y_N but reduces Y_S. However, the former effect dominates the latter, as shown in (5a) and (5b). On the tariff revenue, we have

$$\frac{\partial R}{\partial\theta_N}=t_N\frac{\partial Y_S}{\partial\theta_N}=-\frac{t_N}{3p'}r_N f_N^{'}<0\,, \tag{16}$$

i.e., an increase in θ_N reduces Southern imports and lowers the tariff revenue.

Invoking condition (15), (16) and (5a) to (5j), the FOCs can be simplified to

$$A_N(\theta_N,\theta_S;v)-\frac{1}{3}(Y_N+Y_S)r_N f_N^{'}-\frac{t_N}{3p'}r_N f_N^{'}=0\,, \tag{14a'}$$

$$A_S(\theta_N, \theta_S; v) = 0\,. \tag{14b'}$$

Comparing (14b') and (7b'), one sees that in the South, the government's best response function is identical to that of the firm. This arises because there is no consumption in the South and national welfare is equivalent to firm profit.

Compared with (7a'), condition (14a') has two more terms which are the combined effects on the consumer surplus and the tariff revenue: the former is positive while the latter is negative. In the absence of the import tariff, the latter disappears, and the Northern government chooses a higher LS than the Northern firm. In Figure 1, the Northern government's best response curve under free trade lies above that of the Northern firm, and the resulted equilibrium under the policy game is at point G. Hence we establish

Proposition 4: *In the absence of the import tariff, the equilibrium of a policy game between the two governments involves in a higher (lower) LS in the North (South) than under free choices of LS.*

One might be surprised that the Southern government would choose a lower LS than the Southern firm. However, this result stems from our assumption that consumption occurs in the North only. By condition (15), a higher LS raises the Northern welfare under free trade. When maximizing national welfare that includes consumer surplus, the Northern government chooses a higher LS than the Northern firm, shifting the Northern government's best response curve to above that of the Northern firm. While in the South, the best response curves are identical for the government and the firm. Thus, the two governments' best response curves cross at point G in Figure 1. That is, as a result of oligopolistic interactions, the North expands its output which requires a higher LS. This in turn eats into the market share of the South, forcing it to lower its LS, since LS is costly to produce. It follows that the LS gap between the two countries increases.

However, if the important tariff t_N becomes sufficiently high, then the tariff-revenue effect (third term in (14a')) can dominate the consumer-surplus effect (second term), shifting the Northern government's best response curve to below that of the Northern firm's, at $\tilde{R}_N^G$. In this case, the new equilibrium would lie at a point K, with a higher LS for the South and a lower one for the North than at point F. In fact it can be shown that,

$$(Y_N + Y_S) + \frac{t_N}{p'} \; > \; (=,<) \; 0 \quad \text{if} \quad t_N < \; (=,>) \; -\frac{1}{\varepsilon P}, \tag{17}$$

where $\varepsilon = (Y_N + Y_S) p'/p$. Therefore we can state:

Proposition 5: *Under a sufficiently high import tariff* $t_N \; > \; -\frac{1}{\varepsilon P}$, *the policy game results in a higher LS for the South and a lower one for the North than under free choices of LS.*

5. International Harmonization

In this section, we examine the issue of LS harmonization. Suppose an official international organization, say the International Labor Organization (ILO), sets a *single* guideline standard, by which all countries are encouraged to abide. There could be many potential objectives, but we assume that the principle in the present model is to maximize the total world welfare. We also assume that under harmonization of worldwide LS, the North cannot impose import tariffs on the South. Hence eq. (3) becomes irrelevant and the tariff revenue is zero.

5.1 Harmonization and World Welfare Maximization

The ILO maximizes an objective function which is the sum of (13a) and (13b) with $\theta_N = \theta_S \equiv \theta_w$. Keeping the notation consistent, we have

$$W(\theta_w, \theta_w; v) = \psi_N(\theta_w, \theta_w; v) + \psi_S(\theta_w, \theta_w; v). \tag{18}$$

The first order condition to maximize (18) with respect to θ_w is

$$\frac{\partial W}{\partial \theta_w} = \frac{\partial W}{\partial \theta_N} + \frac{\partial W}{\partial \theta_S} = A_N + A_S + (\frac{\partial \phi}{\partial \theta_N} + \frac{\partial \tilde{\pi}_S}{\partial \theta_N}) + (\frac{\partial \phi}{\partial \theta_S} + \frac{\partial \tilde{\pi}_N}{\partial \theta_S}) = 0, \tag{19}$$

where $(\frac{\partial \phi}{\partial \theta_N} + \frac{\partial \tilde{\pi}_S}{\partial \theta_N}) + (\frac{\partial \phi}{\partial \theta_S} + \frac{\partial \tilde{\pi}_N}{\partial \theta_S}) = \frac{(Y_N - Y_S) f'(\theta_w)(r_S - r_N)}{3} < 0$, because the following conditions hold: $r_S > r_N \Leftrightarrow Y_S < Y_N$ and $r_S < r_N \Leftrightarrow Y_S > Y_N$. Equation (19) then implies

$$A_N(\theta_w, \theta_w; v) + A_S(\theta_w, \theta_w; v) > 0, \tag{19'}$$

which leads to,

Lemma 1: *Suppose that the world welfare maximizing LS* $\theta_w (= \theta_N = \theta_S)$ *exists, then it must lie on the 45 degree line below point* H *in Figure 2(a).*

Proof: In Figure 2(a), curves R_N and R_S are the best response curves of firms N and S, respectively. We have $A_N + A_S < 0$ at point H since $A_N = 0$ and $A_S < 0$. By continuity of $A_N(\theta_w, \theta_w; v) + A_S(\theta_w, \theta_w; v)$ in θ_w, there exists a point I on the 45 degree line below point H such that $A_N(\theta_S^I, \theta_S^I; v) + A_S(\theta_S^I, \theta_S^I; v) > 0$. ■

Note that even though the total world welfare includes Northern consumer surplus, point I lies not above but below point H on the 45 degree line, because if θ_w rises, Y_N increases but Y_S decreases and their net effects on Northern consumer surplus are cancelled out. Thus the Northern firm's best response curve not that of the Northern government is crucial for establishing point I.

Lemma 1 implies that if an international organization such as the ILO imposes a common LS in both countries to maximize total world welfare, then the initially freely chosen Northern LS must be lowered. In other words, it is not binding for the North, who will choose a higher LS instead. Specifically, as long as the abided by LS is lower than θ_S^H in Figure 2(a), firm N will voluntarily choose a LS on its best response curve R_N, i.e., point I', resulting in $\theta_N^{I'}$. On the other hand, this minimum LS is binding for the South, because it is higher than the Southern LS at point F.

5.2 The Uniform, Binding Minimum LS

The uniform LS always lies on the 45 degree line. By Lemma 1, the minimum, uniform LS that is binding in both countries must lie at point H. This gives rise to

Proposition 6: *Under the uniform, minimum LS that is binding for both countries, world welfare is not maximized.*

This Proposition implies that it is not efficient to enforce a common LS in both countries, given that their wage-technology ratios are different. In Figure 2(a), using iso-profit curves, it is straightforward to show that the North obtains a higher profit and welfare at point F than at point H, since its iso-profit curve is concave to the northwest. However, that of the South is ambiguous. As shown in Figure 2(a), depending on the shape of its iso-profit curve, the South's profit and welfare may be higher at point H than at F, or the opposite may arise. If the former case is obtained, then the South benefits from the binding minimum LS.

6. First-Best Labor Standards

In this section, we allow the ILO to set different LS for each country, to maximize the world total welfare, rather than each's national welfare—Pareto efficiency. As before, free trade prevails under worldwide harmonization of LS. Then the game is identical to the previous sections except in stage two, it is the ILO which determines the LS. As such, equations (5a) to (5h) should all remain valid.

The world welfare can be written as

$$W(\theta_N, \theta_S; v) = \psi_N(\theta_N, \theta_S; v) + \psi_S(\theta_N, \theta_S; v), \qquad (20)$$

where $\psi_N(\theta_N, \theta_S; v)$ and $\psi_S(\theta_N, \theta_S; v)$ are defined by (13a) and (13b), respectively.

The ILO sets possibly two different LS for the two countries. The first order conditions to maximize (20) are

$$\frac{\partial W}{\partial \theta_N} = \frac{\partial \psi_N}{\partial \theta_N} + \frac{\partial \psi_S}{\partial \theta_N} = A_N + \frac{\partial \phi}{\partial \theta_N} + \frac{\partial \tilde{\pi}_S}{\partial \theta_N} = 0, \qquad (21a)$$

$$\frac{\partial W}{\partial \theta_S} = \frac{\partial \psi_S}{\partial \theta_S} + \frac{\partial \psi_N}{\partial \theta_S} = A_S + \frac{d\phi}{d\theta_S} + \frac{\partial \tilde{\pi}_N}{\partial \theta_S} = 0, \qquad (21b)$$

where $\partial \phi / \partial \theta_i = -(Y_N + Y_S) r_i f_i^{'} / 3 > 0$ and $\partial \tilde{\pi}_j / \partial \theta_i = 2 Y_j r_i f_i^{'} / 3 < 0$ when $p'' = 0$.

Let us now compare the first best LS with the freely chosen LS. Under the freely chosen LS, we have $A_N = 0$ and $A_S = 0$ on the best response curves of firms N and S respectively. Notice that at the equilibrium point F, $\theta_N > \theta_S$. And by condition (5a), $Y_N > Y_S$. Substituting these into (21a) and (21b), we must have $\partial W / \partial \theta_N = (Y_S - Y_N) r_N f_N^{'} / 3 > 0$ on the best response curve of firm N, and $\partial W / \partial \theta_S = (Y_N - Y_S) r_S f_S^{'} / 3 < 0$ on that of firm S. These imply that the first best LS must lie above curve R_N and below curve R_S in Figure 1.

Next we compare the first best LS with that under the policy game. Under the latter, $\partial \psi_N / \partial \theta_N = A_N + \partial \phi / \partial \theta_N = 0$ and $\partial \psi_S / \partial \theta_S = A_S = 0$, as given in (14a') and (14b'). Then we have $\partial W / \partial\theta_N = 2Y_S r_N f_N^{'} / 3 < 0$ and $\partial W / \partial\theta_S = (Y_N - Y_S) r_S f_S^{'} / 3 < 0$. These imply that the first best LS must lie below both curves R_S and R_N^G.

Combining the two comparisons above, one sees that the first best LS must lie below curve R_S, and between curves R_N and R_N^G, e.g., as at point O in Figure 1. Summarizing these results, we can state,

Proposition 7: *(i). In the South, the first best LS is lower than the one in the regime of free choices of LS; (ii). In the North, it lies in the area between curves* R_N *and* R_N^G*, but to the left of* R_S*. Thus, the first best combination of LS must lie in the area* ABFG *in Figure 1.*

By Proposition 7, suppose we start from point G, then lowering the LS slightly increases the welfare for both countries. This result seems surprising. It is derived purely based on efficiency considerations, without any value judgment. If one introduces Southern LS into either country's welfare function (i.e., due to human rights concerns), then the first-best policy and harmonization would call for a higher LS in the South, and Proposition 7 must be revised.

7. Technology Transfer

The previous section has shown that (i) the internationally harmonized, binding minimum LS may lower Northern profits and welfare; (ii) under the first best LS, the Southern LS is too low. In this section, we consider an alternative policy, namely LS technology transfer. If the Northern superior technology of producing LS is transferred to the South, can we improve national and world welfare?

Suppose the Northern superior technology c_N $(< c_S)$ of producing LS is transferred to the South such that the actual Southern technology becomes

$$\breve{c}_S = (1-\delta)c_S + \delta c_N \,, \qquad (22)$$

where $\delta \in [0,1]$ indicates the fraction of technology transferred from the North. We also assume that for each unit of LS produced using the new technology, the Southern firm must pay a unit cost of $e \geq 0$ to the Northern firm. Then the Northern and Southern profit functions become respectively

$$\breve{\pi}_N(Y_N, Y_S; \theta_N, \theta_S; t_N, v, e) \equiv pY_N - w_N L_N - c_N\theta_N + e\theta_S \,, \qquad (23a)$$

$$\breve{\pi}_S(Y_N, Y_S; \theta_N, \theta_S; t_N, v, e) \equiv (p - t_N)Y_S - w_S L_S - (\breve{c}_S + e)\theta_S \,, \qquad (23b)$$

where $v \equiv (c_N, c_S, r_N, r_S)$ is the vector of parameters as before.

We examine only the case of free choices of LS. In the final stage, the two firms play a Cournot output game. The FOCs (4a) and (4b) and the comparative statics results (5a)~(5j) still apply. Thus we can rewrite the outputs as functions of LS, $Y_i \equiv Y_i(\theta_N, \theta_S; e, \delta; t_N, v) = \breve{Y}_i(\bullet)$.

In the first stage, each firm chooses its own LS to maximize profits. Using the envelope theorem, the FOCs can be obtained as:

$$\breve{A}_N(\theta_N, \theta_S; t_N; v) = A_N(\theta_N, \theta_S; t_N; v) = 0 \,, \qquad (24a)$$

$$\breve{A}_S(\theta_N, \theta_S; t_N; v; e, \delta) \equiv \frac{4}{3}(\tau_1 - r_S f_S^{'})\breve{Y}_S - (\breve{c}_S + e) = 0 \,. \qquad (24b)$$

In terms of functional forms, these FOCs differ from (7a’) and (7b’) only in (24b), where the unit cost of technology transfer *e* enters negatively, and δ enters $\breve{c}_S$ as in (22). They yield the best response functions

$$\breve{\theta}_N = \theta_N(\theta_S; e, \delta; v, t_N), \tag{24a'}$$

$$\breve{\theta}_S = \theta_S(\theta_N; e; \delta; v, t_N), \tag{24b'}$$

which determine the Nash equilibrium levels of LS . In Figure 1, the Northern firm's best response curve can still be represented by R_N , but that of the Southern firm becomes $\breve{R}_S$, which lies to the right of the original one R_S without technology transfer. The distance between $\breve{R}_S$ and R_S depends on the parameters *e* and δ , the former of which reduces it while the latter raises it. These can be confirmed by totally differentiating (24a) and (24b), yielding:

$$T\frac{d\breve{\theta}_S}{de} = -\{\frac{\partial \breve{A}_S}{\partial e}\frac{\partial \breve{A}_N}{\partial \breve{\theta}_N} - \frac{\partial \breve{A}_N}{\partial e}\frac{\partial \breve{A}_S}{\partial \breve{\theta}_N}\} < 0, \tag{25a}$$

$$T\frac{d\breve{\theta}_S}{d\delta} = -\{\frac{\partial \breve{A}_S}{\partial \delta}\frac{\partial \breve{A}_N}{\partial \breve{\theta}_N} - \frac{\partial \breve{A}_N}{\partial \delta}\frac{\partial \breve{A}_S}{\partial \breve{\theta}_N}\} > 0, \tag{25b}$$

where $T = \begin{pmatrix} \frac{\partial \breve{A}_N}{\partial \breve{\theta}_N} & \frac{\partial \breve{A}_N}{\partial \breve{\theta}_S} \\ \frac{\partial \breve{A}_S}{\partial \breve{\theta}_N} & \frac{\partial \breve{A}_S}{\partial \breve{\theta}_S} \end{pmatrix} > 0$, $\frac{\partial \breve{A}_N}{\partial e} = \frac{\partial \breve{A}_N}{\partial \delta} = 0$, and $\frac{\partial \breve{A}_S}{\partial e} < 0$, $\frac{\partial \breve{A}_S}{\partial \delta} > 0$.

In particular, provided that *e* is not too large such that there is positive technology transfer, then we can find a combination of the parameters of *e* and δ , which gives rise to an $\hat{R}_S$ passing through a point such as T in Figure 1. And point T must lie on the segment between points F and H on curve R_N. The appeal is that at point T, the Southern LS is higher and the Northern one lower than at point F, which both firms choose voluntarily without any action by governments or international organizations. Recall that this is what the ILO tried to achieve through international harmonization in earlier sections. In addition, compared with point H, the Northern profits and welfare are higher at T. Therefore we can state:

Proposition 8: *Under positive technology transfer from the North to the South, the Southern firm voluntarily raises its LS, and the Northern profits and welfare are higher, compared with the case of the uniform, binding minimum LS.*

Note that the technology transfer equilibrium is more efficient than at H, because the South uses better technology. It follows that the world total welfare is also higher. In addition, since the Southern firm must pay a positive unit cost of technology transfer, in equilibrium, we always have $\breve{\theta}_N > \breve{\theta}_S$ under free choices of LS.

8. Concluding Remarks

Everyone agrees that improving living standards in the South is desirable. The question is how to achieve this. Our model shows that the South adopts a lower LS because its technology is inferior (more exactly its wage-technology ratio is higher), rendering it to have lower labor productivity. The equilibrium of a policy game requires an even higher LS for the North and a lower one for the South under free trade, but exactly the opposite arises if the Northern tariff is high. These results are derived under efficiency considerations, and imply that the Northern LS is not feasible for the South.

However, equity requires that both countries adopt a more or less equal LS. Point H is completely equitable, but not efficient. A more efficient solution is technology transfer, resulting in equilibrium point T, which is more equitable than points F and G. Moreover, at T, every party including the North is better off.

The paper also demonstrates that trade restrictions do not work either. Loss of access to markets in the North hampers the growth prospects of the South and thereby retards the upgrading of its LS. Trade sanctions are thus likely to be counterproductive as a means of encouraging improvements in labor standards. On the other hand, providing incentives for the South to raise its LS may work effectively.

Incorporating human rights may narrow the LS gap between the two countries. Suppose Southern LS θ_S enters Northern welfare ψ_N (eq. (13a)) directly such that $\frac{\partial \psi_N}{\partial \theta_S} > 0$, as claimed by human rights groups. Note that Northern LS does not enter directly because LS in developed countries has reached a certain threshold level, enabling the government not to worry about it. Then since the best response curves of LS are negatively sloped, national welfare maximization requires the North to adopt a lower LS than when θ_S does not enter ψ_N directly. This reduces its marginal product of labor in final production and hence its output. As a consequence, price rises, inducing the Southern firm to invest more in LS, thus narrowing the LS gap between the two countries. In addition, since an increase in the import tariff reduces Southern LS (Proposition 2), lowering Northern welfare, it is better not to impose the tariff to force the South to adopt a higher LS, contrary to the claims of human rights groups.

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Appendix Comparative Statics under Free Choices of LS

Total differentiation of (7a') and (7b') yields

$$\begin{pmatrix} \frac{\partial A_N}{\partial \theta_N} & \frac{\partial A_N}{\partial \theta_S} \\ \frac{\partial A_S}{\partial \theta_N} & \frac{\partial A_S}{\partial \theta_S} \end{pmatrix} \begin{pmatrix} d\theta_N \\ d\theta_S \end{pmatrix} = -\begin{pmatrix} \frac{\partial A_N}{\partial \tau_0} \\ \frac{\partial A_S}{\partial \tau_0} \end{pmatrix} d\tau_0 + \begin{pmatrix} \frac{\partial A_N}{\partial \tau_1} \\ \frac{\partial A_S}{\partial \tau_1} \end{pmatrix} d\tau_1 - \begin{pmatrix} \frac{\partial A_i}{\partial c_i} \\ \frac{\partial A_j}{\partial c_i} \end{pmatrix} dc_i - \begin{pmatrix} \frac{\partial A_N}{\partial r_i} \\ \frac{\partial A_S}{\partial r_i} \end{pmatrix} dr_i ,$$

$\forall\ i, j = N, S,\ i \neq j$.   The terms

$$\frac{\partial A_N}{\partial \theta_N} = -\frac{4}{3} r_N f_N^{'} \frac{\partial Y_N}{\partial \theta_N} - \frac{4}{3} r_N Y_N f_N^{"} < 0, \quad \text{and}$$

$$\frac{\partial A_S}{\partial \theta_S} = \frac{4}{3}(\tau_1 - r_S f_S^{'}) \frac{\partial Y_S}{\partial \theta_S} - \frac{4}{3} r_S Y_S f_S^{"} < 0,$$

are the second order conditions for profit maximization. They are negatively signed as long as $f_S^{"}$ is "large", a condition usually required in stage games. Here specifically we need $\gamma_i \equiv r_i Y_i f_i^{"} + 2(r_i f_i^{'})^2 / 3p' > 0$. We also have

$$\frac{\partial A_N}{\partial \theta_S} = -\frac{4}{3} r_N f_S^{'} \frac{\partial Y_N}{\partial \theta_S} < 0,$$

$$\frac{\partial A_S}{\partial \theta_N} = \frac{4}{3}(\tau_1 - r_S f_S^{'}) \frac{\partial Y_S}{\partial \theta_N} < 0.$$

Thus, the determinant is calculated as

$$D = \begin{vmatrix} \frac{\partial A_N}{\partial \theta_N} & \frac{\partial A_N}{\partial \theta_S} \\ \frac{\partial A_S}{\partial \theta_N} & \frac{\partial A_S}{\partial \theta_S} \end{vmatrix} = -\frac{16}{9} r_N f_N^{'} (\tau_1 - r_S f_S^{'}) E - \frac{4}{3} r_S Y_S f_S^{"} \frac{\partial A_N}{\partial \theta_N} - \frac{4}{3} r_N Y_N f_N^{"} \frac{\partial A_S}{\partial \theta_S} \; > \; 0,$$

where $E = \{\frac{\partial Y_N}{\partial \theta_N} \frac{\partial Y_S}{\partial \theta_S} - \frac{\partial Y_N}{\partial \theta_S} \frac{\partial Y_S}{\partial \theta_N}\} \; = \; \frac{r_N f_N^{'}}{3(p')^2} (r_S f_S^{'} - \tau_1) > 0$, using (5a)~(5d).

It is straightforward to calculate the following,

$$\frac{\partial A_N}{\partial t_N} = -\frac{4}{3} r_N f_N^{'} \frac{\partial Y_N}{\partial t_N} > 0 \,,$$

$$\frac{\partial A_S}{\partial t_N} = \frac{4}{3} (\tau_1 - r_S f_s^{'}) \frac{\partial Y_S}{\partial t_N} < 0 \,,$$

$$\frac{\partial A_i}{\partial c_i} = -1 \,,$$

$$\frac{\partial A_i}{\partial c_j} = 0 \,,$$

$$\frac{\partial A_i}{\partial r_j} = -\frac{4}{3} r_i f_i^{'} \frac{\partial Y_i}{\partial r_j} > 0, \quad i = N, S, \;\; i \neq j \,,$$

$$\frac{\partial A_N}{\partial r_N} = -\frac{4}{3} Y_N f_N^{'} + \frac{2}{3} (\tau_1 - 2 r_N f_N^{'}) \frac{\partial Y_N}{\partial r_N} \,,$$

$$\frac{\partial A_S}{\partial r_S} = -\frac{4}{3} Y_S f_S^{'} + \frac{4}{3} (\tau_1 - r_S f_S^{'}) \frac{\partial Y_S}{\partial r_S} \,,$$

$$\frac{\partial A_N}{\partial \tau_1} = -\frac{4}{3} r_N f_N^{'} \frac{\partial Y_N}{\partial \tau_1} > 0 \,, \;\; \text{if} \;\; \underline{\theta} > \theta_S \,,$$

$$\frac{\partial A_S}{\partial \tau_1} = \frac{4}{3} Y_S + \frac{4}{3} (\tau_1 - r_S f_S^{'}) \frac{\partial Y_S}{\partial \tau_1} \quad \begin{cases} < 0 & \text{if} \;\; \underline{\theta} >> \theta_S \\ > 0 & \text{if} \;\; \underline{\theta} \approx \theta_S \end{cases}$$

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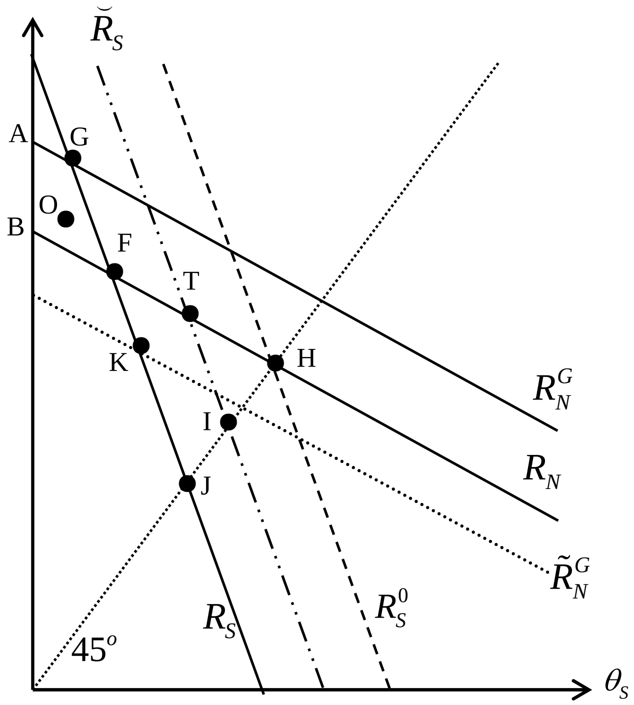

Figure 1

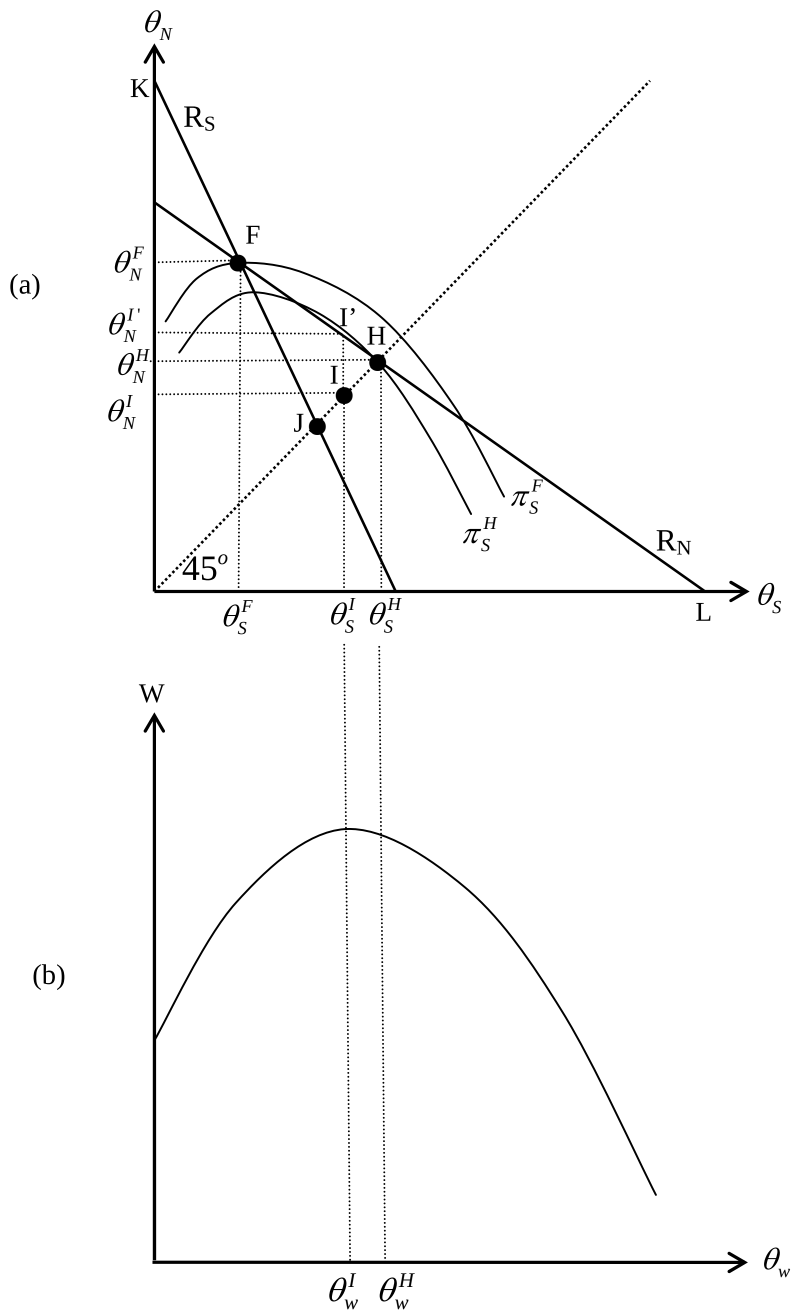
(a)
θ_N
K
R_S
F
θ_N^F
$\theta_N^{I'}$
I'
H
θ_N^H
I
θ_N^I
J
π_S^F
π_S^H
R_N
45^o
θ_S^F
θ_S^I
θ_S^H
L
θ_S
(b)
W
θ_w
θ_w^I
θ_w^H

Figure 2