Trade Policy in the Presence of Technology Licensing*

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Abstract

This paper reconsiders strategic trade policy when a high-cost and a low-cost firm belonging to different countries compete a la Cournot in a third country market and technology is transferable. Assuming technology is transfered via licensing, optimal export policy is characterized. Apart from affecting product-market profits - which is standard in this literature, any subsidy or tax, also affects the licensing decision and surplus generated from licensing in our framework. Interestingly enough, an increase in subsidy by the high-cost country's government raises the surplus while the surplus is lowered by an increase in subsidy by the low-cost country's government.

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1 Introduction

There has been a great deal of research regarding strategic trade policy over the last two decades. A central result in this literature[1] is that export subsidy is optimal when two firms of different countries engage in Cournot competition in a third country market. Subsequent work[2] has shown that the sign and magnitude of policy crucially depends on factors like nature of oligopolistic competition (Cournot vs.Bertrand), number of firms (relative number of foreign and home firms) and ownership of firms.

These models share a common framework - firms either compete in quantities or prices and prior to this product-market competition, government(s) credibly commit to subsidy rate(s). However, these models abstract from the possibility of technology transfer prior to product market competition. This paper considers trade policy in an environment where technology transfer is feasible. We assume that technology is transferred via licensing and that the license fee cannot be taxed directly[3]. A major difference of this paper from the standard literature is that any subsidy or tax, in addition to shifting profits also affects transactions regarding technology transfer.

We consider a high-cost and a low-cost firm belonging to different countries in the third-country model of strategic trade policy literature and re-examine rent-seeking incentives for government intervention in the presence of technology transfer. The central result of this paper is that often the subsidy levels are lower when technology transfer is feasible compared to when technology transfer is infeasible. In fact, for a range of cost parameters the optimal policy for the government of the high-cost firm might be to tax its own firm.

In our framework, in addition to its effect on profits, there are two additional effects of a subsidy - effect on surplus of licensing(which the two firms share) and the effect on the subsidy bill. With reasonable restrictions on profit function, an additional unit of subsidy by the high-cost country's government raises the surplus while an additional unit of subsidy by the low-cost country's government lowers it. Hence, from the surplus perspective, the high cost country's government wants to increase the subsidy while the low-cost country's government wants to lower it. However the incentives are reversed when we consider the effect on the subsidy bill. For any

[1] Brander and Spencer(1985)

[2] See Eaton and Grossman(1986)

[3] A similar assumption has been made for example in Brander and Spencer(1987).

given subsidy rate, the subsidy bill for the high-cost country following technology licensing is higher compared to the case when licensing is infeasible and hence the high-cost country's government wants to lower subsidy. On the other hand,the subsidy bill is lower following licensing for the low-cost country for any subsidy rate. The differences in the effects on the subsidy bill between two countries is due to the fact that the output produced by the high-cost(low-cost) firm is larger(smaller) following technology transfer. Since the 'surplus effect' and the 'subsidy-bill effect' work in opposite directions for each country, the net effect seems to be ambiguous in general and depends on the way the surplus is shared. We find that unless the high-cost firm earns a large share of the surplus, the optimal subsidy in our framework should be lower than the Brander-Spencer subsidy - the optimal subsidy when licensing is not feasible. In particular, if the surplus is split equally the optimal subsidy is lower than the Brander-Spencer subsidy.

It is worth mentioning that the optimal subsidy for the high-cost country is not only lower compared to the Brander-Spencer subsidy rate but for a wide range of values of surplus-sharing parameter[4]optimal policy is a tax. With licensing, a tax brings more revenue to the high-cost country's government because of the higher output produced by its national firm. This incentive to tax outweighs the incentive to subsidize when the beneficial effects of subsidy are small - i.e. when the high-cost firm earns a low share of the surplus. Thus, licensing apart from strategic complementarity or joint profit maximization, provides a rationale for taxation in strategic trade policy models.

Unlike the existing results in the literature on strategic trade policy with asymmetric costs[5], we find that generally there exists a non-monotone relationship between cost-differences and the subsidy level. In the absence of licensing, Neary(1994) has shown in the context of linear demand and constant marginal cost that optimal subsidy of a government increases with the cost-competitiveness of the national firms - that is, a government subsidizes "winners" more generously. The intuition for this is simple. Consider the firm with lower marginal cost. The larger the difference in costs, the higher the comparative advantage of this firm in profit-shifting and hence the higher the subsidy it receives. In our framework however, there are two sources of rents - surplus from licensing and profits - which respond differently to an

[4]For linear demand and constant marginal cost as long as the high-cost firm earns less than 55% we find that there exist cost parameters such that the optimal subsidy might actually be negative.

[5]See Neary(1994), Collie(1993) etc.

increase in the subsidy rate. An increase in the subsidy rate by the low-cost country's government lowers the surplus and the magnitude of the 'surplus effect' is increasing in cost-difference. This suggests why the low-cost firm might actually receive a lower subsidy the more efficient it is. The non-monotonicity is borne out most strikingly in the optimal subsidy schedule of the high-cost firm where we find that the efficient high-cost firm might be taxed and the relatively inefficient high-cost firms might be subsidized.

The main discussion in the paper focuses on the rent-shifting motive in Cournot-competition in the presence of licensing. However the effects are qualitatively similar in the case of Bertrand competition with differentiated products. One important difference between Cournot and Bertrand competition with differentiated products is that the high-cost country's government might want to ban licensing under Cournot competition while it will never do so under Bertrand-competititon with the reverse being true for the low-cost country's government.

The issue of trade policy in the presence of technology licensing is particularly important in the wake of the recent trend for globalization. Trade is no longer equivalent to imports or exports of merchandise. Mergers and acquisitions (M&A's) and technology transfer are major components of cross-border collaborations. The growing number[6] of technology transfers in general and trans-national transfers in particular, is clear from the following excerpt from Nadiri[7](1991)

"In the past few years the pace of technology transfers has been increasing rapidly, particularly among the OECD countries. Statistics on international payments for patents, licenses and technical know-how among the OECD countries have been growing substantially.......... For Japan and U.K. the total transaction between 1970 to 1988 increased by about 400%, France and the U.S. experienced an increase of about 550% while West Germany had a spectacular increase of over 1000% between 1979 and 1988."

Apart from the obvious connection with the strategic trade policy literature, this paper is also related to the literature on technology transfer. The

[6]It is worth emphasizing that the numbers for licensing prior to 1970s are not small either. See Contractor(1981) for details.

[7]This is taken from Baumol(1993). Also look at Scherer(1994, pp59-60) where he discusses(although in a different context) how Pohang Iron and Steel Company in South Korea moved to the technological frontier by licensing technology from Japan.

technology transfer literature[8] has generally focussed on technology transfer between firms of the same country. In contrast to this paper, license fee is not important for welfare considerations in such cases. Though there has been welfare analysis for different mechanisms to license technology, there is hardly any analysis of Pigouvian policies in the context of licensing - especially when the licensee and the licensor belong to two different countries. Thus our paper also extends the licensing literature.

The paper is organized as follows. Section 2 lays down the framework of our model. Section 3 discusses the relationship between licensing and the subsidy rates. Section 4 characterizes the unilaterally optimal policies both for the high-cost and the low-cost country and compares it with the Brander-Spencer subsidy. Section 5 considers simultaneous policy-making by both governments. Section 6 examines the robustness of the results obtained in Cournot-framework in price competition with differentiated products. Section 7 concludes suggesting further extensions. Proofs of the Lemmas and the Proposition are in the Appendix.

2 Model

2.1 Environment

We consider a Cournot duopoly with a homogeneous product where the two firms belonging to different countries compete in a third country market[9].

Technology: Production technology of a firm is a pair - $(c, K) \in \Re^2$ where $c \geq 0$ denotes the constant marginal cost of production and $K > 0$ denotes the fixed cost. Fixed costs are assumed to be appropriately large. Marginal cost $c \in \{c_l, c_h\}$ where $c_h > c_l \geq 0$. Initial technologies of the two firms are assumed to be different. The firm, starting off with $c_h(c_l)$ will be referred to as high-cost(low-cost) firm and the country that the firm belongs to will be referred to as the high cost(low-cost)country. We also assume that $c_h < p_m(c_l)$ where $p_m(c_l)$ refers to the monopoly price with low-cost firm as the sole producer.

[8] See Katz and Shapiro(1985), Kamien and Tauman(1986), Gallini(1984) etc.

[9] It is true that cross-border strategic alliances are made usually to increase market share and to fight aggressively against other competitors. However, we focus on two firms to keep things simple and abstract from effects of competition and coalition formation.

Technology is transferable - i.e. the low-cost firm(firm l hereafter) can transfer its low-cost technology to the high cost firm(firm h hereafter)[10]. The mode of technology transfer is licensing. Low-cost firm licenses the technology to its high-cost rival for a fee. Details of the licensing mechanism are described in the next subsection(2.2).

Demand: We assume that the inverse demand[11] for the homogeneous product in the third country market is given by

$$p = a - x_h - x_l \tag{1}$$

where x_h and x_l refers to the output produced by firms h and l respectively.

2.2 The Game

Sequence of Events: The timing of events is given by the following three-stage game. In the third and final stage of the game, the two firms engage in Cournot-Nash competition in the product market of the third country. Prior to product market competition, in the second stage of the game, the firms decide whether to undertake technology transfer or not and the license fee associated with technology transfer. In the first stage, government(s) simultaneously decide on subsidy rates they would offer to their national firms. The details of the game are described below.

Product market competition[Stage 3]: Given subsidy rates by the governments(s_h, s_l), licensing decision(d) and license fee F(if any), firms' optimization problem in the duopoly subgame are

$$Max_{x_h \in \Re_+}\ \pi_h = (a - x_h - x_l - m_h)x_h \tag{2}$$

$$Max_{x_l \in \Re_+}\ \pi_l = (a - x_h - x_l - m_l)x_l \tag{3}$$

[10]For simplicity, we assume that when firm l licenses its low-cost technology to firm h, there is no retooling cost borne by firm h.

[11]Some of our results can be obtained by imposing reasonable restrictions on the reduced-form profit functions. This is discussed in following sections. Finding out the class of demand functions for which our result holds remains a topic of further research.

where $m_l = c_l - s_l$ and

$$m_h = \begin{cases} c_l - s_h & \text{if technology islicensed} \\ c_h - s_h & \text{if technology is not licensed} \end{cases}$$

Equations(2) and (3) describe the profit maximization problems of firm h and firm l respectively. The m_i's can be interpreted as the effective marginal cost of production of a firm. Though the firms start with c_i's, the marginal costs that enter into a firm's profit-maximization problem in the third stage take into account also the subsidy and constant-cost technology it actually uses (which is different from the initial one for firm h if there is licensing) and is captured by m_i.

Licensing[Stage 2]: Prior to the product market competition firm l can license its low-cost technology to h for a fixed[12] fee(F). Notice that licensing takes place only if joint profits in the presence of licensing is higher than joint profits in the absence of licensing. We use the term joint profits to denote the sum of profits of the two firms resulting from the non-cooperative Cournot-duopoly in Stage 3. We denote joint profits by $(\Pi) = \pi_h + \pi_l$. Surplus from technology licensing(if any) is $D = \Pi(L) - \Pi(NL)$ where $\Pi(L)$ and $\Pi(NL)$ denotes joint profits with licensing and no licensing respectively. Let α denote the share of surplus(D) accruing to the licensee[13]. The relation between F, D and α is captured in the following equation:

$$\pi_h(L) - F = \pi_h(NL) + \alpha[\Pi(L) - \Pi(NL)] \tag{4}$$

Rearranging (4) we could express the license fee as:

$$F = (1-\alpha)[\pi_h(L) - \pi_h(NL)] + \alpha[\pi_l(NL) - \pi_l(L)] \tag{5}$$

Notice that $\alpha = 0$ implies a take-it-or-leave-it offer to by the firm l while $\alpha = 1$ implies take-it-or-leave-it offer by the firm h. Rents(R) of firm h and firm l are $R_h = \pi_h + Fd$ and $R_l = \pi_l - Fd$ respectively where

[12]Allowing for royalties along with a fixed fee leads to the possibility of collusion - A suitable non-linear pricing scheme can be devised such that only one of them produces and the firms split up the monopoly profit. As Katz and Shapiro(1985) has pointed out that this kind of behavior is likely to violate anti-trust laws and hence we rule out use of non-linear schemes.

[13]In co-operative game theory language, the licensing stage is essentially a generalized Nash-bargaining game with profits earned by the firms in absence of licensing($\pi_i(NL)$) as the threat points.

$$d = \begin{cases} 1 & \text{if technology licensed} \\ 0 & \text{if technology not licensed} \end{cases}$$

Thus, total rents for the firm l (the licensor) is the sum of product market profits and the license fee while for firm h(the licensee) rents is product market profits net of the license fee.

Subsidy setting stage[Stage 1]: In the first stage of the game, government(s) simultaneously choose subsidies(s). Government i's optimization problem is to choose s_i (given s_j, $i, j \in \{l, h, \}$, $i \neq j$) to maximize welfare (W_i)

$$W_i = R_i - s_i x_i \tag{6}$$

Following Brander and Spencer(1985), welfare is defined as rents net of subsidy bill[14].

2.3 Equilibrium

An equilibrium in our framework is

(a) a pair of subsidy rates - ${s_l}^*$, ${s_h}^*$;

(b) licensing decision $d^* \in \{0, 1\}$ and license fee F^*(if licensing takes place) and

(c) output decisions: ${x_h}^*(m_h, m_l)$, ${x_l}^*(m_h, m_l)$

such that

(i) For any (m_h, m_l); ${x_h}^*(m_h, m_l)$, ${x_l}^*(m_h, m_l)$ is Nash equilibrium of Stage 3 game.

(ii) For any s_h, s_l,

[14]Neary(1994) has defined welfare more generally as [profits - δ subsidy bill] with $\delta > 1$ capturing the fact shadow cost of public funds greater than unity. However in our model, that only increases the possibility of taxation or lower subsidies in equilibrium.We abstract away from such a general formulation to focus on our reasoning for lower subsidies - licensing.

$$\mathrm{d}^* = \begin{cases} 1 & \text{if } D \geq 0 \\ 0 & \text{if } D < 0 \end{cases}$$

(iii) Given $s_j{}^*$, $s_i{}^*$ solves government i's optimization problem in Stage 1 where $i, j \in \{l, h, \}$, $i \neq j$.

3 Licensing and Subsidy rate(s)

The departure of our model from the standard Brander-Spencer framework lies in the the fact that any subsidy or tax, in addition to shifting profits also affects the decision and payments regarding licensing. This section focuses on the relationship between subsidy and tranactions regarding technology licensing.

Given the cost parameters (c_h and c_l) and subsidy rates (s_h, s_l) the surplus(D) from technology licensing can be written as

$$D(c_h, c_l; s_h, s_l) = \pi_h(c_l - s_h, c_l - s_l) + \pi_l(c_l - s_h, c_l - s_l) - \pi_h(c_h - s_h, c_l - s_l) - \pi_l(c_h - s_h, c_l - s_l) \tag{7}$$

where $\pi_i(m_h, m_l)$ in (7) is the reduced form profit function incorporating the Nash-equilibrium outputs $x_h{}^*(m_h, m_l)$, $x_l{}^*(m_h, m_l)$ from the Stage 3 game. The reduced-form profit functions are used to discuss the effect of subsidy on the surplus from technology licensing.

Surplus: We focus on the effects of subsidy on the surplus from licensing. It is interesting to note that subsidies by the governments of the high-cost and low-cost country affects the surplus(D) differently. In particular, an increase in subsidy by the high-cost country's government raises the surplus while the reverse is true for the low-cost country. The results in this section are not dependent on any particular demand structure or nature of product market competition. The following proposition characterizes the effect of an increase in subsidy in terms of properties of reduced-form profit function.

Proposition 1:(i) *If* x_h, x_l *are strictly positive,* $\frac{\partial D}{\partial s_h} > 0$ *if* $\frac{\partial^2 \Pi(m_h, m_l)}{\partial {m_h}^2} > 0$.

(ii) If x_h, x_l are strictly positive, $\frac{\partial D}{\partial s_l} < 0$ if $\frac{\partial^2 \Pi(m_h, m_l)}{\partial m_h \partial m_l} < 0$.

Proof: See Appendix. ∎

The condition of negative cross-partials - $\frac{\partial^2\Pi(m_h,m_l)}{\partial m_h \partial m_l} < 0$ - is astandard in the literature. Convexity of joint profits with respect to the of firm h's cost($\frac{\partial^2\Pi(m_h,m_l)}{\partial {m_h}^2} > 0$) is little restrictive. However it holds for linear demand function and henceforth assumed to hold for the rest of the paper.

Licensing Decision: Though Proposition 1 describes the effect of subsidy on surplus from licensing, it does not address how the licensing decision is affected by the subsidy. The following proposition summarizes the relationship between the licensing decision and the subsidy rates.

Proposition 2:(i) *If* $\frac{\partial^2\Pi(m_h,m_l)}{\partial^2 m_h} < 0$, *then for any given* s_l, $\exists$ *a unique* s_h *(say,* $s_{h,C}$*) such that technology is licensed iff* $s_h \geq s_{h,C}$.

(ii) *If* $\frac{\partial^2\Pi(m_h,m_l)}{\partial m_h \partial m_l} > 0$, *then for any given* s_h, $\exists$ *a unique* s_l *(say,* $s_{l,C}$*) such that technology is licensed iff* $s_l \leq s_{l,C}$

Proof: See Appendix. ■

A standard result in the licensing literature is that, when payment scheme is fixed fee, technology is not licensed if differences in costs are too large. With large cost-differences, the low-cost firm enjoys an 'almost-monopoly' position and hence lacks the incentive to share its technology with its rival firm. For any given s_l, an increase in s_h reduces the cost-difference. Proposition 2(i) states that by providing a suitably high s_h (and thereby suitably reducing cost difference) the high-cost country's government can ensure licensing. The opposite is true for the low-cost country's government.

Quality of the licensed technology: Throughout we have assumed that, if technology is licensed, firm l transfers its low-cost technology c_l to firm h. Assuming that the firms can produce at any marginal cost higher than the one it starts with, a natural question to ask is what prevents firm l to license an inferior technology - i.e. a technology with marginal cost of production c where $c \in (c_h, c_l)$. Proposition 3 characterizes the condition[15] for licensing of the best technology, if technology is licensed.

Proposition 3: *If* $\frac{\partial^2\Pi}{\partial {m_h}^2} > 0$, *technology if licensed, is the best one.*

Proof: See Appendix. ■

[15]See Kabiraj and Marjit(1992) for a discussion on quality of licensed technology in context of trade

4 Unilateral Policy-making

This section considers the cases where one of the country's government provides subsidy strategically to its own firm to maximize welfare while the other country's government remains passive. Without loss of generality, we assume that the passive government sets subsidy to zero. The discussion below characterizes the optimal unilateral subsidies and compares it with the unilateral Brander-Spencer subsidy rates - the optimal subsidy rates in absence of possibility of licensing. Relationship between cost-differences and the optimal subsidy is also explored.

4.1 The high-cost country

In this subsection, we consider optimal subsidy for government of the high-cost country when the other government does not subsidize its national firm.

Let s denote specific subsidy provided by the high-cost country's government. Note that the high-cost firm receives this subsidy for every unit of output it produces(x_h) irrespective of whether it buys the technology from the low-cost firm or not.

4.1.1 Characterization

To facilitate the characterization of the optimal subsidy rates, we consider two hypothetical regimes - (1) a regime where licensing is compulsory - CL - and (2)a regime where licensing is banned - BL. Let W_{CL} and W_{BL} denote the welfare with compulsory licensing and banned licensing regime respectively. Incorporating the output decisions in Nash-equilibrium from the Cournot game, it follows from the definition of welfare in (7) that

$$W_{BL} = \pi_h(c_h - s, c_l) - sx_h(c_h - s, c_l) \tag{8}$$

$$W_{CL} = \pi_h(c_l - s, c_l) - F - sx_h(c_l - s, c_l) \tag{9}$$

Using (5), which expresses fee in terms of surplus(D) and a sharing rule(α) and rearranging the various terms we get

$$W_{CL} = W_{BL} + \alpha D - s[x_h(c_l - s, c_l) - x_h(c_h - s, c_l)] \quad (10)$$

For a given subsidy rate, welfare in compulsory licensing regime is welfare in absence of licensing plus the share of surplus it receives less the dis-savings in subsidy bill. We denote $s_{BL} = argmax_{s\in\Re}W_{BL}$, $s_{CL} = argmax_{s\in\Re}W_{CL}$ $s_C = s_{h,C}$ when $s_l = 0$ and s_O be the optimal subsidy with no government restrictions on licensing - the optimal subsidy rate in our framework. Note that s_{BL} is the Brander-Spencer subsidy rate(s_{BS}) - the optimal subsidy in the absence of licensing. s_C is the critical subsidy rate when the low-cost country's government has set subsidy to zero. Though the comparison between s_{BL} and s_{CL} require information on demand structure and α - the share of surplus accrued to the licensee, we can claim the following

Lemma 1:$s_O \in \{s_{BL}, s_{CL}, s_C\}$[16]

Proof: See Appendix. ■

From Lemma 1, it follows that the optimal subsidy in our framework will either be one of the optimal subsidy rates in the hypothetical regime and or if one of these rates violate the constraint(see Proposition 2(i)) it is possible that critical subsidy rate will be optimal. Obviously, if both s_{CL} and s_{BL} violate the constraint - e.g.. if $s_{CL} < s_C < s_{BL}$ then the critical subsidy rate will be optimal(at least in the limit). Can we say anything more about s_O? Proposition 4 provides a partial characterization s_0 based on comparisons between the three possible candidates - s_{BL}, s_{CL}, s_C.

Proposition 4: Define $S = \{s_{BL}, s_{CL}, s_C\}$.
(i)If $s_C = maxS$ then $s_O = s_{BL}$, provided $s_C > 0$.
(ii)If $s_C = minS$ then $s_O = s_{CL}$, provided $s_C < 0$
(iii)If s_C is neither $maxS$ nor $minS$ then $s_O = s_C$ provided $s_{BL} = maxS$.

Proof: See Appendix. ■

Characterization of the optimal subsidy in the proposition above is fairly

[16]Strictly speaking s_C in some case is the limit subsidy. Whether s_C is optimal or optimal in the limit depends on what assumption we make regarding licensing decision when $D = 0$.

intuitive. Consider 4(i). Suppose the critical subsidy rate is higher than other two rates. Note that licensing takes place only if the subsidy rate is higher than s_C. Given that $s_{CL} < s_C$ and assuming that the welfare expression is trictly concave in the subsidy rate maximum welfare with licensing occuring in equilibrium will be achieved at s_C. However by definition, at s_C, the firms are indifferent between licensing and no-licensing and hence the surplus from licensing is zero. Welfare will be higher by providing a subsidy infinitesimally smaller than s_C since there will be reduction in subsidy bill. Welfare will be even higher by providing a s_{BL} since s_{BL} is the optimal subsidy in absence of licensing. Similar intuition can be provided for 4(ii) and 4(iii).

4.1.2 Comparison with Brander-Spencer subsidy:

Given the dependence of the value of s_O on s_C, a comparison between Brander-Spencer subsidy rate(s_{BS}) and s_O might seem difficult. The following lemma states the condition under which comparison between unconstrained subsidy rates suffices.

Lemma 2: Provided $s_{BS} > 0$, $s_{CL} < s_{BL} \Rightarrow s_O < s_{BS}$.

Proof: See Appendix. ■

Given Lemma 2, a natural question to ask is, when is $s_{CL} < s_{BL}$ - i.e. when is the optimal subsidy under compulsory licensing regime lower than the optimal subsidy under the regime when licensing is banned? A general answer is when the firm h earns low share of the surplus. An increase in subsidy raises the surplus but it also raises dis-savings from the subsidy bill. Consider the extreme case where $\alpha = 0$ - the high cost firm does not earn any share of the surplus. The high-cost country's government does not have any incentive to raise the subsidy because marginal benefit of subsidy does not change from the no-licensing situation. The marginal cost is higher in terms of larger subsidy bill due to higher output produced by the high-cost firm following licensing. This points towards lower subsidies.

In our discussion so far we have not assumed any particular demand structure. All our results hold if welfare functions in the hypothetical regimes are strictly concave and reduced-form profit functions satisfy the property mentioned in Proposition 1. However, at this stage it seems necessary to impose structure on demand to proceed further. The rest of the discussion in this subsection assumes the linear demand structure mentioned in (1).

Straightforward calculations show that for $p = a - (x_h + x_l)$,

$$s_{BL} = (a - c_l)(1 - 2\gamma)/4 \tag{11}$$

$$s_{CL} = (a - c_l)[(1 - 2\gamma)/4 + \gamma(10\alpha - 6)/4] \tag{12}$$

$$s_C = (a - c_l)(5\gamma - 2)/10 \tag{13}$$

where $\gamma = \frac{c_h - c_l}{a - c_l}$. Comparing (11) and (12) it follows from Proposition 4 that for $\alpha < 0.6$, optimal subsidy in the presence of licensing is always lower than the Brander-Spencer subsidy. In particular, if the surplus is split equally, then the optimal subsidy is lower than the Brander-Spencer subsidy.

Proposition 5: *With linear demand, if $\alpha < 0.6$, $s_O \leq s_{BS}$.*

Proof: See Appendix. ■

To illustrate the possibility of taxation we consider a special case - $\alpha = 0$ i.e. where high-cost firm do not earn any share of the surplus or alternatively the low-cost firm makes-it a take-it-or-leave-it offer.

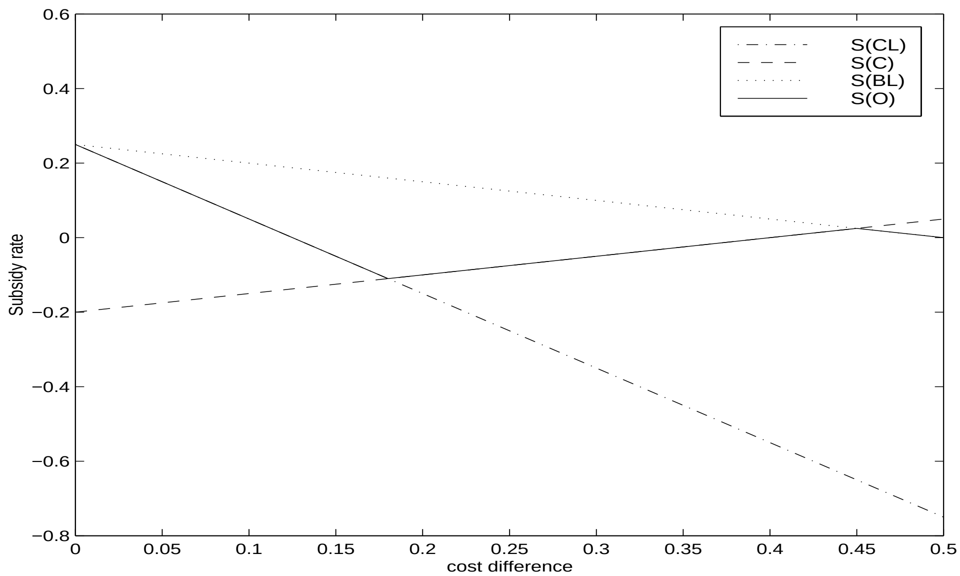
In case of take-it-or-leave-it offer by the the low-cost firm the optimal subsidy rate for the high-cost country's government is

$$s_O = \begin{cases} (a - c_l)(1 - 8\gamma)/4 & \text{if } \gamma < 0.18 \\ (a - c_l)(5\gamma - 2)/10 & \text{if } 0.18 \leq \gamma \leq 0.45 \\ (a - c_l)(1 - 2\gamma)/4 & \text{if } 0.45 < \gamma < 0.5. \end{cases}$$

The optimal subsidy schedule is drawn in Figure 1 assuming $a - c_l = 1$. From the expression for optimal subsidy schedule it follows that a tax might be optimal. Consider $\gamma = 0.2$. Since $0.18 \leq \gamma \leq 0.45$, $s_O = (a - c_l)(5\gamma - 2)/10$. Evaluating at $\gamma = 0.2$, $s_O = -(a - c_l)/10 < 0$.

Though the result is illustrated with $\alpha = 0$, the possibility of export taxation is more general. In particular even with equal division of surplus there exist cost parameters for which the optimal policy is a tax. Proposition 6 states the condition on surplus-sharing where the optimal policy is a export tax.

Figure 1: Optimal Subsidy schedule of the high-cost country



Proposition 6: *With linear demand, $\forall \alpha < 0.55$, there exists cost-parameters for which optimal subsidy might be negative! - i.e. optimal policy might be a tax.*

Proof: See Appendix. ■

Our work provides a novel reasoning for tax - licensing. This is different from the other rationale provided in the literature for export taxation - joint profit maximization, price competition etc. The reasoning is simple. Consider the case where firm h do not earn any share of the surplus. With firm h firm not earning any share of the surplus there is no marginal benefit from licensing while the marginal cost is higher because of the higher subsidy bill corresponding to any subsidy rate. This reduces the incentive to subsidize and hence subsidy is lower. In fact, the optimal subsidy can become so low that it might actually become negative. So the optimal policy might be a tax. Another way (and possible the more meaningful way)of thinking about why the optimal policy might be a tax is as follows. Since with licensing, output produced by the firm h is higher the high-cost country's government has a incentive to set tax. On the other hand, an increase in subsidy raises the surplus. If firm h has weak bargaining power(low α) then government's incentive to subsidize its national firm is reduced. It sets a tax ensuring that technology is licensed. This is as if when the national firm cannot grab much of the surplus, the government is grabbing some of the surplus in the form of increased tax revenue.

4.1.3 Relationship between cost-competitiveness and subsidy level:

In the context of linear demand and constant marginal cost framework Neary(1994) has shown that the greater the cost-advantage (or less cost-disadvantage) of a firm the higher the subsidy it receives. Neary's argument is - "the more cost competitive is the home firm(in this section the high-cost firm) at the margin, the greater is its comparative advantage in profit shifting and hence greater the pay-off to subsidizing it."

This relationship is not generally true in our framework. Notice from Figure 1, for $0.4 \leq \gamma \leq 0.45$, higher the cost-differences higher is the subsidy which is due to the fact the critical subsidy rate(s_C) is increasing in cost-differences(γ) and for the range of cost-parameters mentioned critical subsidy rate is optimal. Neary's result is entirely reversed if we consider $\alpha = 1$ - the high-cost firm makes a take-it-or-leave-it offer. With $\alpha = 1$, $s_O = s_{CL} = (a - c_l)(a + 2\gamma)/4$. It follows straightway that optimal subsidy is increasing in degree of inefficiency(measured by the differences in marginal cost). The higher is the cost-differential the higher the subsidy the high-cost firm receives. Using (7) with linear demand structure, we get $\frac{\partial D}{\partial s} = 10(a - c_l)\alpha\gamma$. The marginal increase in surplus due to an additional unit of subsidy increases with cost-differences and greater the value of α the greater is this effect. From the perspective of surplus, the high-cost country's government has an incentive to increase subsidy the more disadvantageous is its home firm and with $\alpha = 1$, this incentive dominates the incentive to lower subsidy due to the comparative-advantage in profit-shifting argument. Though it is possible to find values of α such that Neary's result go through in our framework the relationship between cost-differences and the optimal subsidy levels is non-monotone. Probably more striking than non-monotonicity in our framework is the fact that inefficient firms of the high-cost country might be subsidized while relatively less inefficient firm might be taxed. Consider $\alpha = 0$ and $\gamma = 0.45$. From the expression for s_O, it follows that for $\gamma = 0.45$ $s_O = (a - c_l)(1 - 2\gamma)/4 = (a - c_l)/40 > 0$. At $\gamma = 0.2$, $s_O = -(a - c_l)/10 < 0$. This feature - government does not necessarily pick winners - actually holds for other values of α as well.

Proposition 7: *With linear demand, $\forall \alpha < 0.55$, there exists a pair of γ's depending on α - $\gamma_1(\alpha)$, $\gamma_2(\alpha)$ - such that $\gamma_1(\alpha) < \gamma_2(\alpha)$ and $s_O(\gamma_1) < 0 < s_O(\gamma_2)$*

Proof: See Appendix. ■

4.2 The low-cost country

The framework and the timing of the events is the same as in the previous section. The only difference is that the low-cost country's government chooses subsidy to maximize welfare while the high-cost country's government does not subsidize or tax its national firm.

Let s denote specific subsidy provided by the high-cost country's government. Firm l receives this subsidy for every unit of output it produces(x_l) irrespective of whether it sells its technology to the firm h or not. We will be brief in discussing the issues which are similar to the previous section.

4.2.1 Characterization

Let W_{CL} and W_{BL} denote welfare with compulsory licensing and banned licensing regime respectively.

$$W_{BL} = \pi_l(c_h, c_l - s) - s x_l(c_h, c_l - s) \tag{14}$$

$$W_{CL} = \pi_l(c_l, c_l - s) + F - s x_l(c_l, c_l - s) \tag{15}$$

Using (14) and (5), W_{CL} can be written as

$$W_{CL} = W_{BL} + (1-\alpha)D + s[x_l(c_h, c_l - s) - x_l(c_l, c_l - s)] \tag{16}$$

where $1-\alpha$ denote the share of surplus accruing to the firm l. For a given subsidy rate, welfare in compulsory licensing regime is welfare in absence of licensing plus the share of surplus it receives plus the savings in subsidy bill. We denote $s_{BL} = argmax W_{BL}$, $s_{CL} = argmax W_{CL}$, $s_C = s_{l,C}$ with $s_h = 0$

and s_O be the optimal subsidy with no government restrictions on licensing - the optimal subsidy rate in our framework.

Lemma 1*: $s_O \in \{s_{BL}, s_{CL}, s_C\}$

Proof: See Appendix. ■

Proposition 4* provides a partial characterization s_O based on comparisons between the three possible candidates - s_{BL}, s_{CL}, s_C.

Proposition 4*: Define $S = \{s_{BL}, s_{CL}, s_C\}$.
(i)If $s_C = maxS$ then $s_O = s_{CL}$, provided $s_C > 0$
(ii)If $s_C = minS$ then $s_O = s_{BL}$, provided $s_C < 0$
(iii)If s_C is neither $maxS$ nor $minS$ then $s_O = s_C$ provided $s_{CL} = maxS$.

Proof: See Appendix. ■

Consider 4*(i). Suppose the critical subsidy rate is higher than other two rates. Note that licensing can only take place with subsidy rate lower than s_C. Since $s_{BL} < s_C$, surplus is non-negative and subsidy bill is lower compared to the no-licensing which implies welfare with s_{BL} is higher with licensing. Given that $s_{BL} = argmaxW_{BL}$ and $s_{CL}<s_C$, highest welfare will be achieved at s_{CL}. Similar intuition can be provided for 4*(ii) and 4*(iii).

4.2.2 Comparison with Brander-Spencer subsidy

Suppose we find, comparing the optimal subsidies in the two hypothetical regimes, that $s_{CL} < s_{BL}$ - i.e. optimal subsidy with compulsory licensing is lower than the optimal subsidy when licensing is banned. Does this suffice to conclude that optimal subsidy in presence of licensing is lower than the Brander-Spencer subsidy rate - optimal subsidy in absence of licensing. The following result states that it does suffice if the Brander-Spencer subsidy rate(s_{BS}) is positive. Note that $s_{BL} = s_{BS}$.

Lemma 2*: *Provided* $s_{BS} > 0$, $s_{CL} < s_{BL} \Rightarrow s_O \leq s_{BS}$.

Proof: See Appendix. ■

Generally, s_{CL} is lower than s_{BL} - when the high-cost firm earns low share of the surplus. An increase in subsidy lowers the surplus but it also increases the savings from the subsidy bill. Any further characterization requires some information regarding demand structure. We assume the demand to be linear for the rest of this subsection.

Straightforward calculations show that for inverse demand function given by $p = a - (x_h + x_l)$,

$$s_{BL} = (a - c_l)(1 + \gamma)/4 \tag{17}$$

$$s_{CL} = (a - c_l)[(1 + \gamma)/4 - \gamma(8(1 - \alpha) - 3)/4] \tag{18}$$

$$s_C = (a - c_l)(2 - 5\gamma)/8 \tag{19}$$

Comparing (17) and (18), it follows from Proposition 4*, that for $\alpha < 0.625$, optimal subsidy in presence of licensing is always lower than Brander-Spencer subsidy. In particular, if surplus is split equally then the optimal subsidy is lower. However, $s_{CL} > s_{BL}$ is not enough to prove otherwise. In fact, with linear demand optimal subsidy in the presence of licensing is always lower.

Proposition 5*: *With linear demand, $s_O \leq s_{BS}$ irrespective of values of α*

Proof: See Appendix. ■

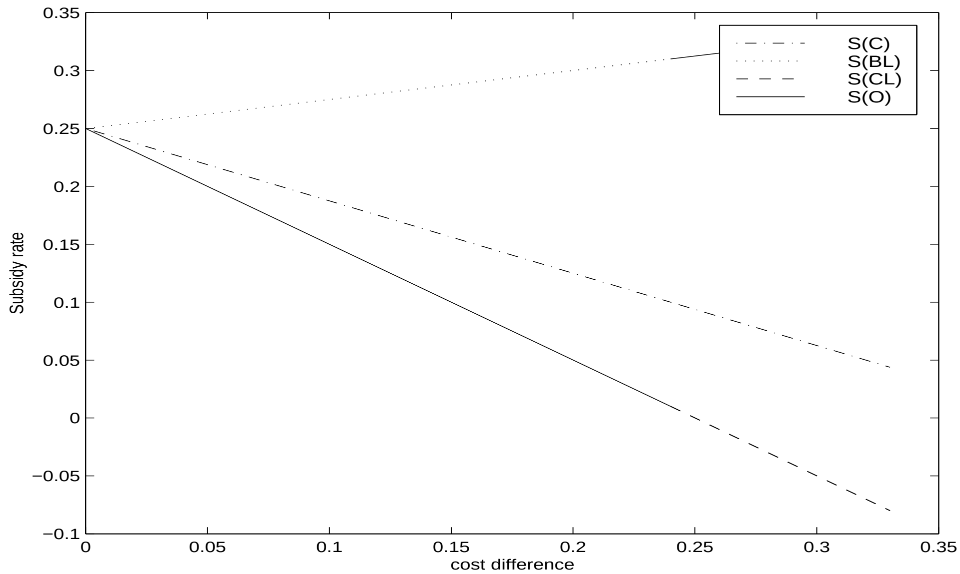
4.2.3 Relationship between cost-competitiveness and subsidy level

To focus on the relationship between cost-differences and the subsidy level we consider a special case - $\alpha = 0$ i.e. where high-cost firm do not earn any share of the surplus or alternatively the low-cost firm makes a take-it-or-leave-it offer.

In case of take-it-or-leave-it offer by the the low-cost firm the optimal subsidy rate for the low-cost country's government is

$$s_O = \begin{cases} (a - c_l)(1 - 4\gamma)/4 & \text{if } \gamma < 0.24 \\ (a - c_l)(1 + \gamma)/4 & \text{if } 0.24 < \gamma < 0.33. \end{cases}$$

Figure 2: Optimal subsidy schedule of the low-cost country



The optimal subsidy schedule is drawn in Figure 2 assuming $a - c_l = 1$. Though the possibility of taxation does not arise in the linear demand framework the relationship between the cost-differences and the subsidy rate is worth mentioning. The discontinuity in the optimal subsidy schedule should not be too surprising once we recognize that the optimization problem for the government(s) is not a standard concave programming problem.

The positive relationship between cost-competitiveness and subsidy, as pointed out by Neary(1994) holds in our example when it is optimal for the government to offer a subsidy level such that technology licensing does not take place($0.24 < \gamma < 0.33$). For such cases, optimal subsidy is $\frac{(a-c_l)(1+\gamma)}{4}$, which clearly is increasing in cost-competitiveness(γ). However, if licensing transfer takes place at the optimal subsidy level ($\gamma < 0.24$), then in contrast to Neary(1994), optimal subsidy is decreasing in cost-competitiveness of the low-cost firm. To understand this, let us assume that the low-cost firm sells its technology for free. Then, optimal subsidy would be $\frac{a-c_l}{4}$. For a given c_l, relationship between subsidy level and cost-competitiveness will depend on the effect of subsidy level on the license fee. License fee, L is given by

$$L = \frac{4(c_h - c_l)(a - c_h - s)}{9} \tag{20}$$

Note that the license fee is decreasing in the subsidy level and the rate of decrease is increasing in cost-competitiveness of the low-cost firm. Hence, for a given c_l, optimal subsidy is decreasing in the cost-competitiveness of the low-cost firm when technology transfer takes place. The discussion above can be summarized in the following proposition .

Proposition 7*: *With linear demand, $\forall\alpha$, there exists a pair of γ's depending on α - $\gamma_1(\alpha)$, $\gamma_2(\alpha)$ - such that $\gamma_1(\alpha) < \gamma_2(\alpha)$ and $s_O(\gamma_1) > s_O(\gamma_2)$*

Proof: See Appendix. ■

4.3 Welfare consequences for the intervening country

4.3.1 The high-cost country

Since optimal policy requires a lot of information which might be costly to obtain it is imperative to look at welfare gains from pursuing the optimal policy compared to a regime with Brander-Spencer subsidy(since that's optimal in absence of technology licensing). Welfare gains are large for the intermediate values of cost-differences. This is easy to understand once we recognize that for extreme values of cost differences either Brander-Spencer subsidy is optimal, when the cost-differences are extremely large (and licensing does not take place)or optimal subsidy rate is close to the value of Brander-Spencer subsidy, when the cost differences are extremely small. With small cost-differences,the effect of a subsidy on surplus and the subsidy-bill are small as well and hence the optimal subsidy is not too different from the Brander-Spencer subsidy. From Table 1 - which describes the case with $\alpha = 0$ - it is interesting to note that in some cases free trade actually yields higher welfare than the Brander-Spencer regime. The intuition is simple. From Figure 1, it follows that for certain values of cost-differences the optimal policy is a tax. So a free trade, or in other words a regime with zero subsidy is closer to optimum than one with a positive one(Brander-Spencer regime).

4.3.2 The low-cost country

Unlike high-cost country, welfare gains from pursuing the optimal policy are not significant for low-cost country compared to Brander-Spencer regime.

Table 2 displays the welfare gains from pursuing optimal policy with $\alpha = 0$. Once again the welfare gains are higher for intermediate values of cost differences and the reasoning is same as in the previous subsection..

4.3.3 Banning licensing

In our discussion so far we have implicitly assumed that government of the intervening country does not decide whether to allow licensing or not. It chooses a subsidy rate after which firms make decision regarding licensing. Let us consider a stage prior to the subsidy-setting stage where the government can allow(but not force) or ban licensing. Is it possible for a country's government to ban licensing? The question is trivial when there are no Pigouvian interventions (subsidy, taxes etc.) and there is only one firm in each country. No firm will settle for a fee that lowers total rents and hence with any given bargaining power government intervention regarding licensing cannot improve welfare. However in presence of export subsidies/taxes licensing might be banned.

Proposition 8: *Under Cournot competition, low-cost country's government will never ban technology licensing while high-cost country might ban licensing.*

Proof: See appendix. ■

The intuition for Proposition 8 is as follows. For the low-cost country, allowing for licensing, two things can possibly happen -(a) licensing occurs if a Brander-Spencer subsidy is given (b)licensing does not occur with Brander-Spencer subsidy rate. If (b) is true, then allowing licensing cannot be worse than banning it - the low-cost country's government can always allow licensing and provide Brander-Spencer subsidy rate. On the other hand if (a) is true note even if the low-cost firm does not receive any surplus welfare is higher. It follows from the observation that with corresponding to any subsidy rate,and hence corresponding to Brander-Spencer subsidy rate as well, rents are at least as high as with no-licensing and subsidy bill is lower.

High-cost country's government, while intervening unilaterally might find it optimal to ban licensing. Consider Figure 1 with $\alpha = 0$ and $\gamma = 0.1$. $s_O = 0.05$. Here,licensing occurs in equilibrium. However, if licensing is banned, rents received by the high-cost firm is unchanged compared to the situation where licensing is allowed while the subsidy bill is lower with s_O.

This explains why high-cost country's government might want to ban licensing.

5 Policymaking by both the governments

In Brander-Spencer framework, policy-making by both governments is a simple extension of unilateral policy-making case because each countries' profits are affected the same way by an increase in subsidy - given other country's subsidy, a subsidy by a home country's government shifts profits towards its national firm. However, as we have mentioned before, the surplus from licensing is affected differently to an increase in subsidy depending on whether the subsidy is provided by the high-cost country's government or the low-cost country's government. This increases the difficulty of the problem and hence here[17] we focus on linear demand and focus on the whether the results and the intuition obtained in the previous section - where we discuss the unilateral policy-making case - goes through when both governments simultaneously choose subsidies.

We denote the subsidy rates associated with high-cost country and the low-cost country as s^h and s^l respectively. We use s^i_{BL} and s^i_{CL} to denote optimal subsidy rates for country i, $i \in \{l, h\}$ when the licensing is banned(BL) and when the licensing is compulsory(CL). Once again note that s^h_{BL} and s^l_{BL} are the Brander-Spencer subsidy rates. As in the previous sections, we also find here - (i)unless the high-cost firm earns more than half of the surplus generated from licensing (actually close to 60%)subsidy under the compulsory licensing regime should be lower than the subsidy under banned licensing regime,(ii) there exists value of α and range of cost parameters such that (a)the optimal policy for the high-cost country's government is a tax and (b)licensing might be banned by one of the country's government if the governments can choose to allow or ban licensing prior to setting subsidies. A complete characterization of optimal policies will be incorporated in the future versions of the paper.

[17]The future versions of the paper will incorporate a detailed analysis of this problem

6 Price competition

A standard criticism against oligopoly models of trade is that the results are sensitive, among other things, to the mode of product market-competition - whether the firms compete in quantities or prices[18]. So it is important to check the robustness of our results with respect to price competition. Rather than focusing on the details[19] we show the effects shown in Cournot also exist in Bertrand competition with differentiated products. In particular, an increase in subsidy by the high-cost(low-cost) country's government increases(lowers) the surplus while it raises the dis-savings(savings) in subsidy bill.

In Bertrand competition with homogeneous product, there is no incentive to license since in the absence of commitment, product-market profits after licensing will be zero. So a minimal model of product differentiation with two varieties is introduced where each of the varieties is produced by two separate firms (as before one firm is high-cost and and the other one is low-cost). Let the inverse demand curve for variety $i(i, j \in \{l, h\})$ be

$$p_i = a - x_i - \theta x_j \tag{21}$$

where θ measures the degree of product differentiation and $\theta \in (0, 1)$. Denoting s_h and s_l as the subsidy given by the high-cost country and the low-cost country's government respectively, it follows after some algebra that

$$x_h(c - s_h, c_l - s_l) = \frac{(2 - \theta^2)(a - c + s_h) - \theta(a - c_l + s_l)}{(4 - \theta^2)(1 - \theta^2)} \tag{22}$$

$$x_l(c - s_h, c_l - s_l) = \frac{(2 - \theta^2)(a - c_l + s_l) - \theta(a - c + s_h)}{(4 - \theta^2)(1 - \theta^2)} \tag{23}$$

[18]There is a small body of literature which endogenizes the mode of competition and tries to pin down the policies which are welfare improving irrespective of the market structure. Maggi(1996) discusses trade policy with endogenous mode of competition - captured by a capacity-constraint parameter. He finds that capacity subsidies are generally welfare improving irrespective of the nature of competition. Bagwell and Staiger(1994) have obtained similar result for investment subsidies.

[19]In future versions of the paper, we plan to characterize optimal policies with price competition

Plugging $c = c_l$ and $c = c_h$ in (22) it follows that

$$x_h(c_l - s_h, c_l - s_l) - x_h(c_h - s_h, c_l - s_l) = \frac{(2-\theta^2)(c_h - c_l)}{(4-\theta^2)(1-\theta^2)} > 0 \tag{24}$$

Similarly, plugging $c = c_l$ and $c = c_h$ in (23) we find that

$$x_l(c_l - s_h, c_l - s_l) - x_l(c_h - s_h, c_l - s_l) = -\frac{\theta(c_h - c_l)}{(4-\theta^2)(1-\theta^2)} < 0 \tag{25}$$

As in Cournot, high-cost firm's output is higher with licensing($c = c_l$) while the low-cost firm's output is lower.

Corresponding to any given subsidy rate, the subsidy bill in the high-cost country is higher by $s[\frac{(2-\theta^2)(c_h-c_l)}{(4-\theta^2)(1-\theta^2)}]$ in the presence of licensing. This reduces the incentive to increase subsidy[20]. The low-cost country's subsidy bill is lower following licensing. Savings in the subsidy bill is $s[\frac{\theta(c_h-c_l)}{(4-\theta^2)(1-\theta^2)}]$. An increase in s increases the savings in subsidy bill - which provides incentive to the low-cost country's government to increase subsidy.

The sum of profits with licensing($\Pi(L)$ and without licensing ($\Pi(NL)$) in this differentiated products model are given by the following equations

$$\Pi(L) = [\frac{(2-\theta^2)(a - c_l + s_h) - \theta(a - c_l + s_l)}{(4-\theta^2)^2(1-\theta^2)}] + [\frac{(2-\theta^2)(a - c_l + s_l) - \theta(a - c_l + s_h)}{(4-\theta^2)^2(1-\theta^2)}] \tag{26}$$

$$\Pi(NL) = [\frac{(2-\theta^2)(a - c_h + s_h) - \theta(a - c_l + s_l)}{(4-\theta^2)^2(1-\theta^2)}] + [\frac{(2-\theta^2)(a - c_l + s_l) - \theta(a - c_h + s_h)}{(4-\theta^2)^2(1-\theta^2)}] \tag{27}$$

Noting $D = \Pi(L) - \Pi(NL)$, straightforward differentiation yields $\frac{\partial D}{\partial s_h} > 0$, $\frac{\partial D}{\partial s_l} < 0$.

The relationship between the surplus and the subsidy can be traced to Proposition 1. Notice that Proposition 1 states a condition on the reduced -form profit function and not on the product market competition per se. It is easy to check that the joint-profits in this model satisfy those conditions.

[20]In case of a tax this enhances the incentive to raise taxes.

A precise characterization requires comparison of the different subsidy rates (note that with price-competition optimal subsidy is negative) will be incorporated in future versions of this paper. However there is a interesting difference between Bertrand and Cournot-competition in terms of welfare consequences assuming unilateral subsidy-setting. The difference is summarized in the following proposition.

Proposition 9: *Under Bertrand competition with differentiated products, high-cost country's government will never ban technology licensing low high-cost country might ban licensing.*

Proof: See appendix ■

In the absence of licensing, optimal subsidy for the high-cost country's government is negative - therefore the optimal policy is a export tax. We refer to it as the Eaton-Grossman[21] subsidy(s_{EG}). Allowing for licensing welfare with s_{EG} is strictly higher if licensing occurs with s_{EG}. Consider the worst case from the high-cost country's viewpoint - $\alpha = 0$. Even then since $s_{EG}<0$ the welfare is higher due to higher tax revenue. An example for the other case - why the low-cost country might ban licensing is provided in the Appendix.

7 Conclusion

In this paper, we characterize strategic trade policy in the standard third-country model when technology licensing is possible. There are two sources of rents in our framework - product-market profits and surplus generated from licensing. Though the profits for the licensor and the licensee is affected in the same way by an increase in subsidy the surplus generated from licensing responds differently to subsidy given by different governments. In particular, an increase in subsidy by the high-cost country's government increases the surplus while an increase in subsidy by the low-cost country's government lowers the surplus. Despite the differences in effects we find that for a wide range of values for surplus-sharing parameter the optimal subsidy rate chosen by both the governments is lower. In fact, in certain cases we find the optimal

[21]To our knowledge, Eaton and Grosssman(1986) is the first paper that pointed out that optimal policy is a tax in the presence of price-competition

policy to be a tax. This is in contrast to the standard third-country model with two firms and quantity competition where the optimal policy is always a subsidy.

In our framework we also find that unlike Neary(1994), there is no simple monotone relationship between the subsidy a firm receives and its efficiency level. Non-monotonicity is borne out most strikingly with unilateral subsidy-setting by the high-cost country's government. We find that efficient firms might be taxed while relatively less efficient firms might be subsidized - i.e. government(s) does(do) not necessarily pick winners.

Finally, we find that the additional effects of a subsidy in our framework are qualitatively similar in Bertrand and Cournot competition - a feature somewhat unusual in the oligopolistic models. However, there is an important difference between these two modes of competition where we consider that the governments could allow or ban licensing. Assuming unilateral subsidy-setting we have shown that the licensor's country would never ban licensing under Cournot-competition but it might do so under Bertrand competition with the reverse being true for the licensee's country.

We have focussed our discussion on duopoly competition in a third-country market in order to deviate as less as possible from the original Brander-Spencer(1985) framework. Exploring our result with an arbitrary number of firms is particularly important since when technology licensing is infeasible, the number of firms is a crucial factor in determining the sign and magnitude of policy. In our framework with an arbitrary number of firms is that we need to specify the bargaining mechanisms and the conclusions will depend on the assumptions made[22]. We have also abstracted from home

[22]A natural assumption in any trading environment is that if there is one seller and many buyers, then the seller grabs the entire surplus. We conjecture that our results will go through in this case because in duopoly our results hold when the high-cost firm earn low share of the surplus. The result might not hold with several sellers and one buyer. If there are several low-cost firms (all belonging to the same country) and a low-cost firm (belonging to a different country) then the government of the high-cost country will find it optimal to subsidize at a higher rate compared to when technology transfer is infeasible since the surplus is grabbed by the national firm. The government of the low-cost firm would want to subsidize more so that technology transfer does not take place because if licensing occurs the firms will undercut each other in terms of fee. However, if licensing does not occur then government might end up choosing Brander-Spencer subsidy. It is not clear whether subsidy chosen by government of the low-cost firms will be lower or higher. With several high-cost as well as low-cost firms, the problems are compounded and it remains an area for further investigation.

consumption by focussing on third-country market. In presence of home consumption, in addition to the effects mentioned in the paper, we also need to consider the effect of a subsidy on consumer surplus. Moreover we need to include other instruments once we add home consumption. Examining the robustness of results with respect to these two important features is part of our current research[23].

8 Appendix

8.1 Proof of Proposition 1

We rewrite (7) as,

$$D = \pi_h(c_l - s_h, m_l) + \pi_l(c_l - s_h, m_l) - \pi_h(c_h - s_h, m_l) - \pi_l(c_h - s_h, m_l) \tag{28}$$

The result follows noting that

$$\frac{\partial D}{\partial s_h} = \int_{c_l - s_h}^{c_h - s_h} \frac{\partial^2 \Pi(m_h, m_l)}{\partial {m_h}^2} dm_h \tag{29}$$

■

and

$$\frac{\partial D}{\partial s_l} = \int_{c_l - s_h}^{c_h - s_h} \frac{\partial \Pi(m_h, m_l)}{\partial m_l \partial m_h} dm_h \tag{30}$$

■

8.2 Proof of Proposition 2

For a given s_l define

$$s_{h,1} = max\{s : \pi_h(c_h - s, c_l - s_l) = 0\} \tag{31}$$

[23]In future we plan to consider the effect of licensing on R & D subsidies.

$$s_{h,2} = min\{s : \pi_l(c_h - s, c_l - s_l) = 0\} \tag{32}$$

It is straightforward to check that $s_{h,1} < s_{h,2}$ and $D(s_{h,1}) < 0 < D(s_{h,2})$. Existence of $s_{h,C}$ is immediate from the Intermediate Value Theorem while uniqueness follows from the fact $\frac{\partial D}{\partial s_l} > 0$ due to $\frac{\partial^2(\Pi(m_h,m_l)}{\partial {m_h}^2} > 0$. This proves 2(i). Proof of 2(ii) is analogous.

8.3 Proof of Proposition 3

Suppose firm l licenses $c \in (c_h, c_l]$ to firm h. Then

$$D = \pi_h(c - s_h, m_l) + \pi_l(c - s_h, m_l) - \pi_h(c_h - s_h, m_l) - \pi_l(c_h - s_h, m_l) \tag{33}$$

Suppose there exist a $c \in (c_l, c_h)$,say c^* at which D is maximum - i.e. $\frac{\partial D}{\partial c} = 0$ and $\frac{\partial^2 D}{\partial c^2} < 0$ at $c = c*$. However since joint profits is convex in high-cost firm's cost - $\frac{\partial^2 D}{\partial {m_h}^2} > 0$ second order condition cannot be satisfied and hence the claim.

8.4 Proof of Lemma 1

This is obvious once we recognize that the optimization problem for the high-cost country's government can be written as follows

subject to

$$d = \begin{cases} 1 & \text{if } s \geq s_C \\ 0 & \text{if } s < s_C. \end{cases}$$

-1000

8.5 Proof of Proposition 4

Proof of 4(i): Notice since $s_{CL} < s_C$, the possible candidates for optimal subsidies are s_{BL} and s_C. Since at s_C, $D = 0$ $W(s_C) = W(s_C, d = 1) < W(s_C, d = 0)$ where W denotes welfare. However, $W(s_C, d = 0) \leq W(s_{BL}, d = 0) = W(s_{BL})$. The last equality follows from the fact $s_C > s_{BL}$ and hence if s_{BL} is provided $d = 0$ and the technology is not licensed.

Proof of 4(ii): Since $s_{BL} > s_C$, the only possible candidates for equilibrium are s_{CL} and s_C. Since $s_C < 0$, $W(s_C) = W(s_C, d = 1) > W(s_C, d = 0)$. However by definition $W(s_{CL}, d = 1) \geq W(s_C, d = 1)$ and since $s_{CL} > s_C$ the result follows.

Proof of 4(iii): This is obvious since neither s_{BL} nor s_{CL} satisfy the relevant constraint.

8.6 Proof of Lemma 2

Suppose not - i.e. suppose $s_{CL} < s_{BL}$ and yet $s_O > s_{BS}$. So it must be the case $s_O = s_C$. Since $s_{BS} > 0$ and $s_0 > s_{BS}$ it follows that $s_C > s_{BS} > 0$. This contradicts 4(i) and hence the claim.

8.7 Proofs of Proposition 5, 6 and 7

Comparing (11) and (12) and invoking Proposition 4, Proposition 5 follows.

With general $\alpha (\alpha < 0.6)$ the expression for optimal subsidy is as follows.

$$s_O = \begin{cases} (a - c_l)(1 - 8\gamma + 10\alpha\gamma)/4 & \text{if } \gamma < 0.18/(1-\alpha) \\ (a - c_l)(5\gamma - 2)/10 & \text{if } 0.18/(1-\alpha) \leq \gamma \leq 0.45 \\ (a - c_l)(1 - 2\gamma)/4 & \text{if } 0.45 < \gamma < 0.5. \end{cases}$$

Proofs of Propositions 6 and 7 follow from plugging α in appropriate places.

8.8 Proof of Lemma 1*

The proof is almost same as the proof of Lemma 1. The only difference is in specifying the constraint. The optimization problem for the low-cost country's government is subject to

$$d = \begin{cases} 1 & \text{if } s \leq s_C \\ 0 & \text{if } s > s_C. \end{cases}$$

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8.9 Proof of Proposition 4*

Proof of 4*(i): Since $s_{BL} < s_C$, only possible candidates for optimal subsidies are s_{CL} and s_C. Since $s_C > 0$ and at s_C, $D = 0$; $W(s_C, d = 0) < W(s_C, d = 1)$ where W denotes welfare.This implies licensing will occur in equilibrium - i.e. $d = 1$. However, $W(s_C, d = 1) \leq W(s_{CL}, d = 1) = W(s_{CL})$. The last equality follows from the fact $s_C > s_{CL}$ and hence if s_{CL} is provided, $d = 1$ and technology is licensed.

Proof of 4(ii): Since $s_{CL} > s_C$, the only possible candidates for equilibrium are s_{BL} and s_C. Since $s_C < 0$ and at $s_C, D = 0$, $W(s_C, d = 0) > W(s_C, d = 0)$. However, by definition $W(s_{BL}, d = 0) \geq W(s_C, d = 0)$ and since $s_{BL} > s_C$ the result follows.

Proof of 4(iii): This is obvious since neither s_{BL} nor s_{CL} satisfy the relevant constraint.

8.10 Proof of Lemma 2*

Suppose not - i.e. suppose $s_{CL} < s_{BL}$ and yet $s_O > s_{BS}$. So it must be the case $s_O = s_C$. Since $s_{BS} > 0$ and $s_0 > s_{BS}$ it follows that $s_C > s_{BL} = s_{BS}$. This implies $s_C = maxS, s_C > 0$ and yet $s_O = s_C$ which leads to a contradiction of 4*(i). Hence the result.

8.11 Proof of Propositions 5*

If $d = 1$ in equilibrium, then from Proposition 2(ii) it follows that $s_O \leq s_C$. If $d = 0$ in equilibrium then $s_0 \in \{s_C, s_{BL}\}$. To prove Proposition 5*, it suffices to show that $s_C < s_{BL}$. Comparing (17) and (19) we find the $s_C < s_{BL}$ and hence the result.

8.12 Proof of Proposition 8

Suppose the low-cost country's government gives s_{BS}. If $s_{BS} > s_C$ then clearly government can always choose $s_O = s_{BS}$ and licensing will take place. If $s_{BS} < s_C$, then even with $\alpha = 1$ - i.e the low-cost firm does not earn any share of the surplus - $W(s_{BS}, d = 1) > W(s_{BS}, d = 0)$ due to lower subsidy bill with $d = 1$. The result follows from noting that $W(s_O) \geq W(s_{BS}, d = 1)$ and $W(s_{BS}, d = 0)$ is the optimal subsidy in the absence of possibility of licensing.

To prove that the high-cost country's government might want to ban subsidy let's consider the special case $\alpha = 0, \gamma = 0.1$. Direct calculation yields $s_O = (a - c_l)/20$ and $s_C = -3(a - c_l)/20$. However, clearly $W(s_O) = W(s_O, d = 1) < W(s_O, d = 0) < W(s_{BS}, d = 0)$ and hence the result. The equality follows from the fact that licensing occurs in equilibrium since $s_O > s_C$. The first inequality is because of lower subsidy bill in absence of licensing. The second inequality follows from the definition of optimal subsidy.

8.13 Proof of Proposition 9

Suppose the high-cost country's government gives s_{EG}. If $s_{EG} < s_C$ then clearly the high-cost country can always choose $s_O = s_{EG}$ and licensing will not take place and welfare obtained in the absence of licensing can be guaranteed. If $s_{EG} > s_C$, then even with $\alpha = 0$ - i.e firm h does not earn any share of the surplus - $W(s_{EG}, d = 1) > W(s_{EG}, d = 0)$ due to higher tax revenue with $d = 1$. The result follows from noting that $W(s_O) \geq W(s_{EG}, d = 1)$ and $W(s_{EG}, d = 0)$ is the optimal subsidy in the absence of possibility of licensing.

Since we have not spelled out the details of the price-competition framework in our paper, we just mention here why low-cost country's government might want to ban licensing. Suppose $\alpha = 1$ - i.e. firm l does not earn any share of the surplus and $s_{EG} < 0$. Then banning licensing will increase welfare due to increase in tax revenue and there are cases where $W(s_{EG}, d = 0) > W(s_O)$ though if s_{EG} is given without any restriction technology will not be licensed.

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Table 1: Welfare gains for high-cost country

$\gamma = \frac{(c_h - c_l)}{(a - c_l)}$	$G_{FT} = [(W_O/W_{FT}) - 1] * 100$	$G_{BS} = [(W_O/W_{BS}) - 1] * 100$
0.050	5.556	1.333
0.150	1.020	25.714
0.250	25.500	75.236
0.350	48.611	-
0.450	11.111	0.00

Table 2: Welfare gains for low-cost country

$\gamma = \frac{(c_h - c_l)}{(a - c_l)}$	$G_{FT} = [(W_O/W_{FT}) - 1] * 100$	$G_{BS} = [(W_O/W_{BS}) - 1] * 100$
0.010	13.205	0.626
0.050	15.193	2.394
0.100	16.116	3.214
0.150	15.690	2.836
0.200	14.236	1.543
0.230	12.975	0.422
0.250	15.756	0.000

Notes: G_{FT} represent percentage gain in welfare from pursuing optimal policy compared to free trade while G_{BS} represents percentage gain with respect to welfare at Brander-Spencer subsidy level.